



Helioseismology and
Asteroseismology:
Sounding Stars



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University of Birmingham, UK

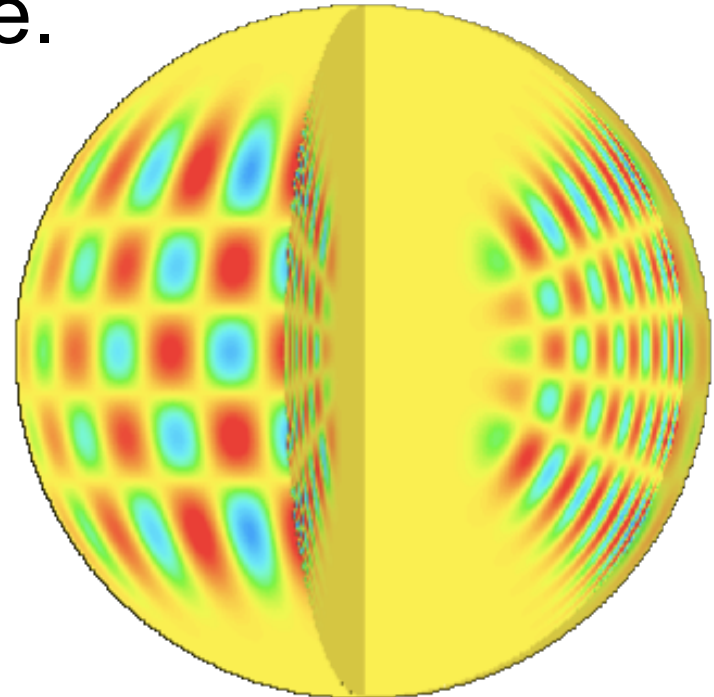
Science on the Sphere Royal Society Meeting, 15 July 2014

helioseismology, *n.*

The study of the sun's interior by the observation and analysis of oscillations at its surface.

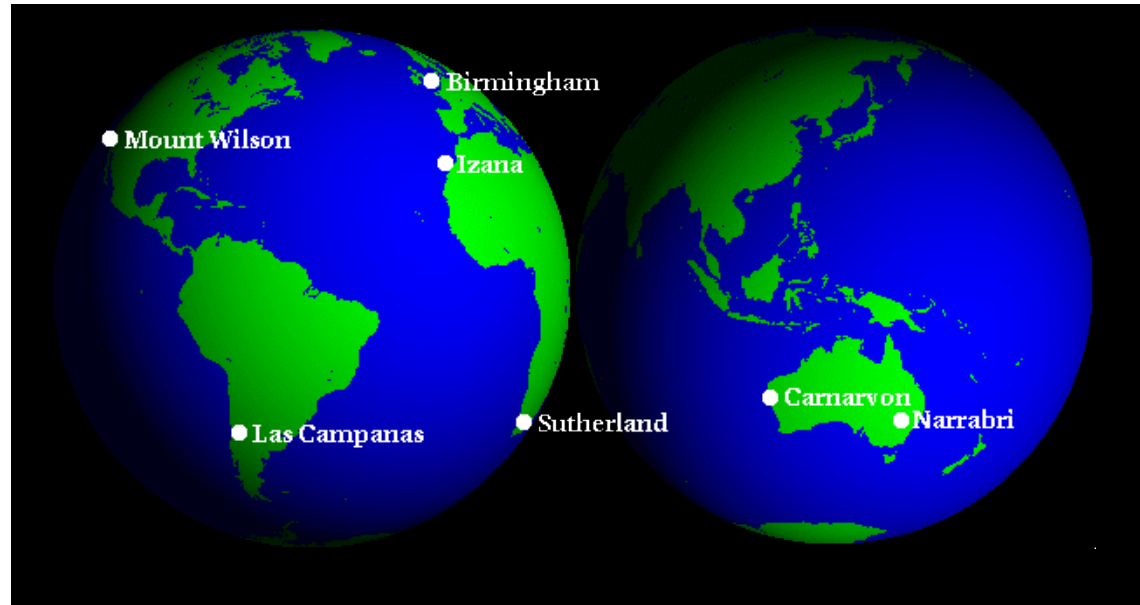
Cf. asteroseismology *n.*

[Oxford English Dictionary]



The Birmingham Solar Oscillations Network

BiSON



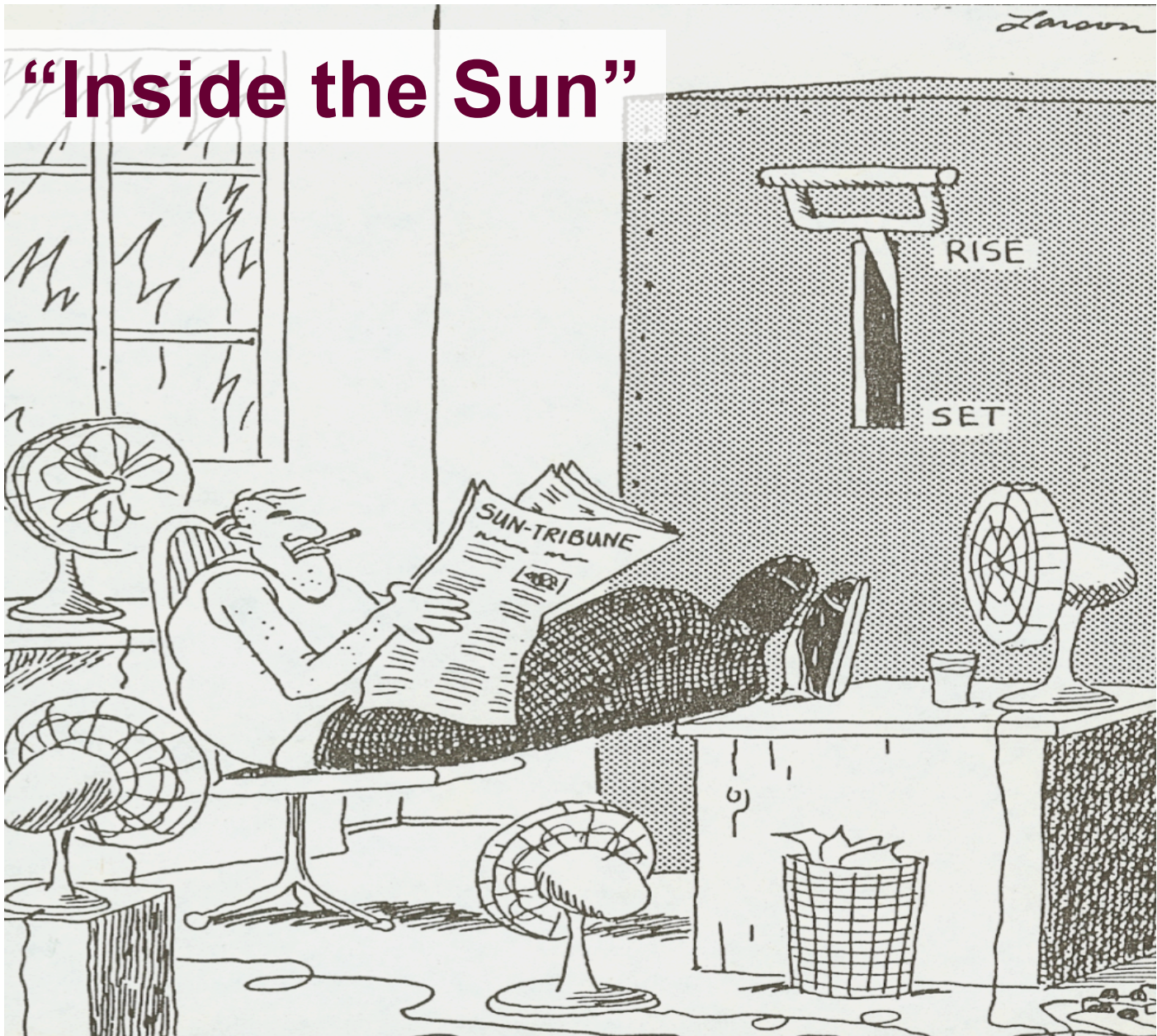
A large, bold, gold-colored number '50' serves as the background for the central text. The number is positioned centrally and takes up most of the vertical space of the page.

NSO Workshop #27

FIFTY YEARS OF
SEISMOLOGY OF THE
SUN & STARS

May 6-10, 2013 • Tucson, AZ, USA

“Inside the Sun”



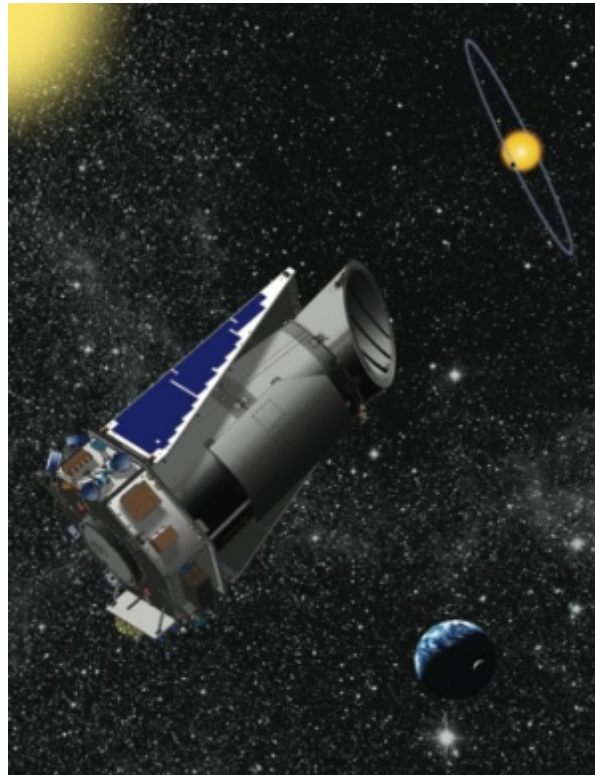
asteroseismology, *n.*

The study of the interior of stars by the observation and analysis of oscillations at their surface.

Cf. helioseismology *n.*

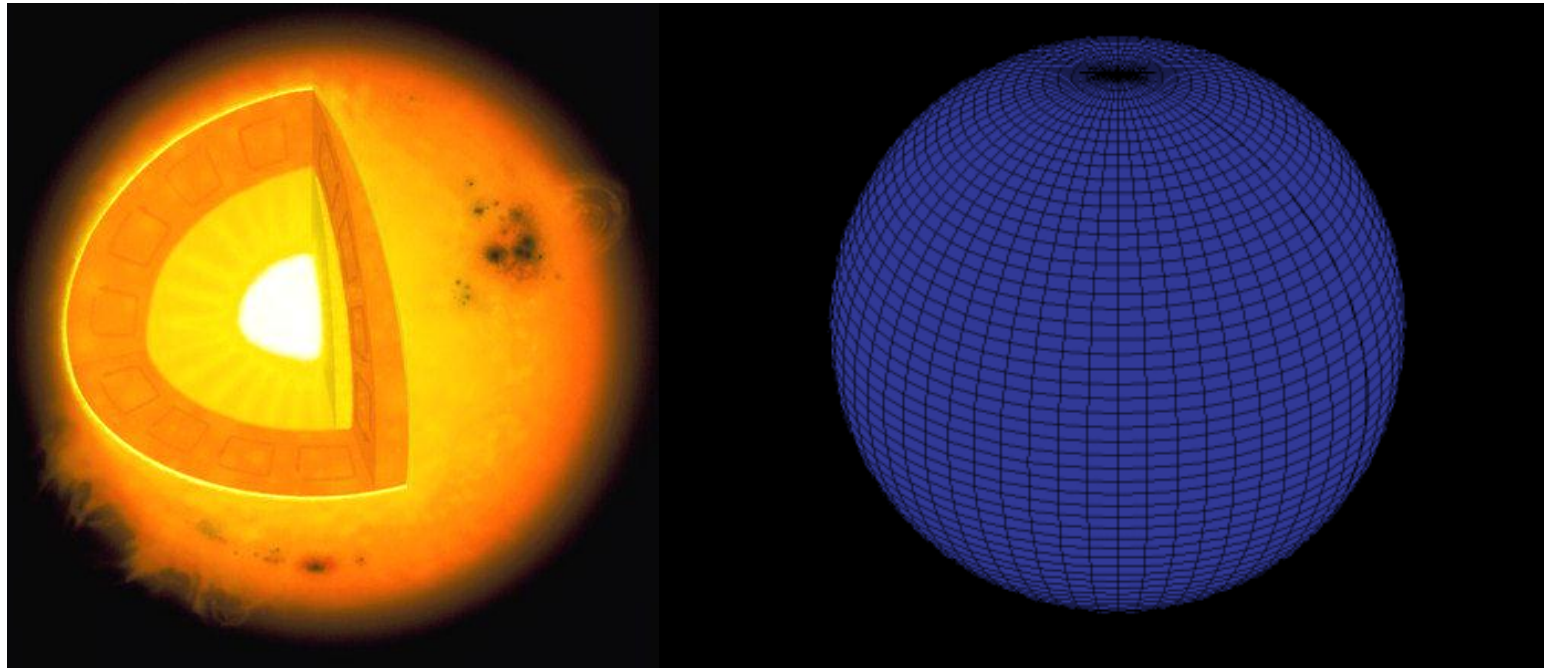
[Oxford English Dictionary]





Solar-like oscillations

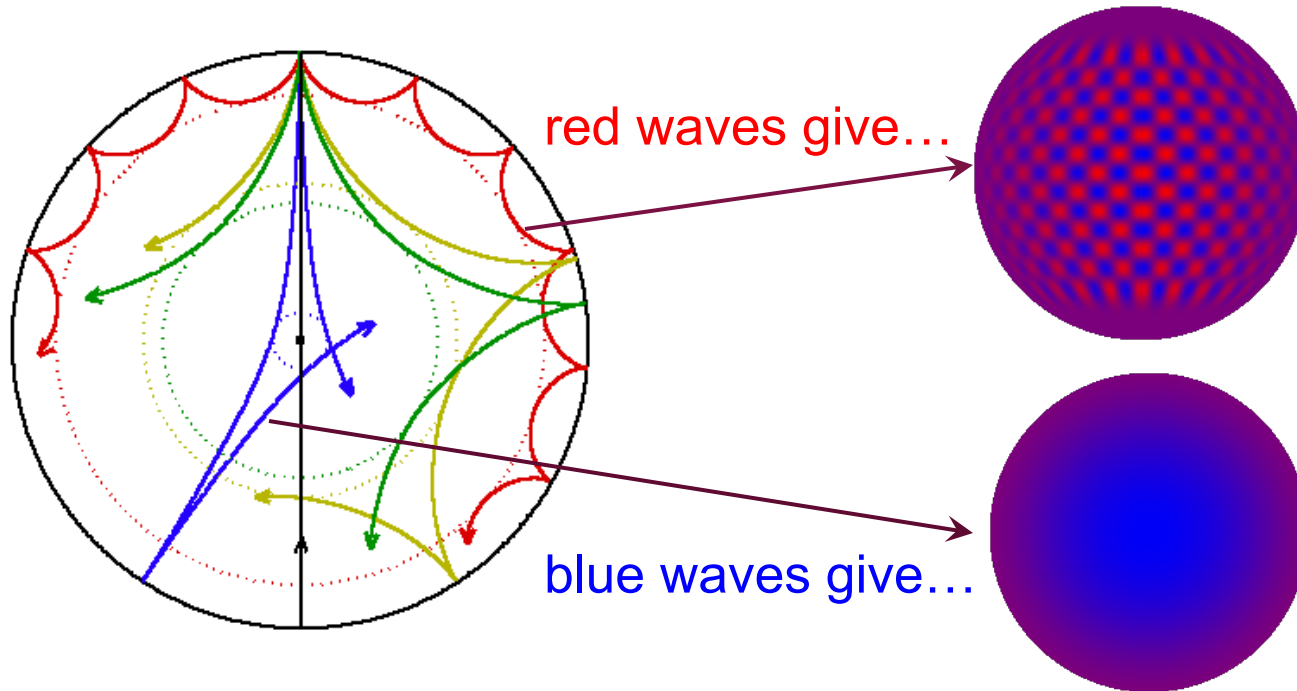
Stochastically excited and intrinsically damped by near-surface convection



Standing acoustic waves

Internal acoustic ray paths

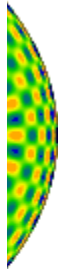
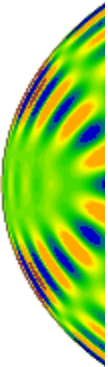
Surface displacement: oscillation patterns in 3D



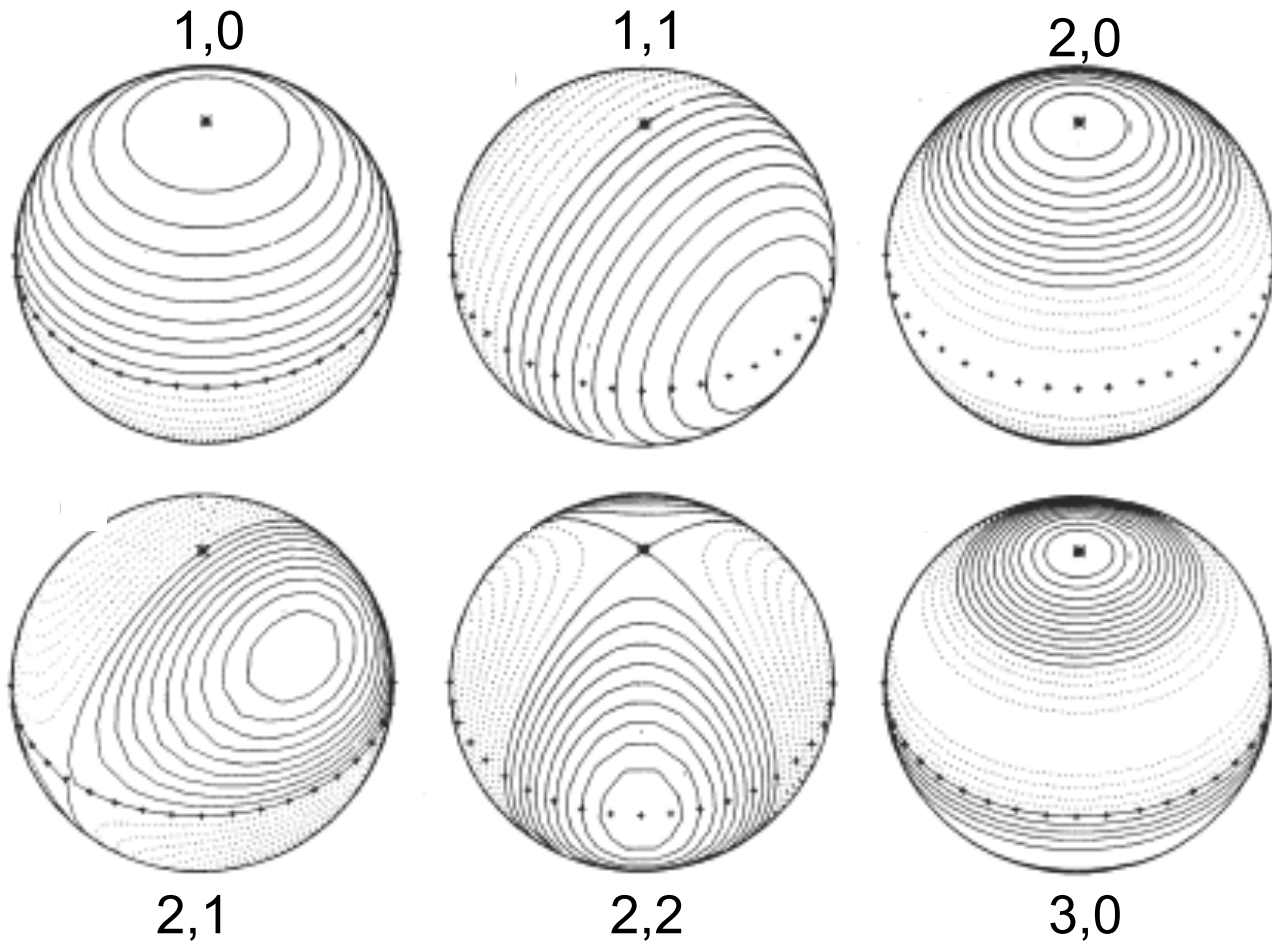




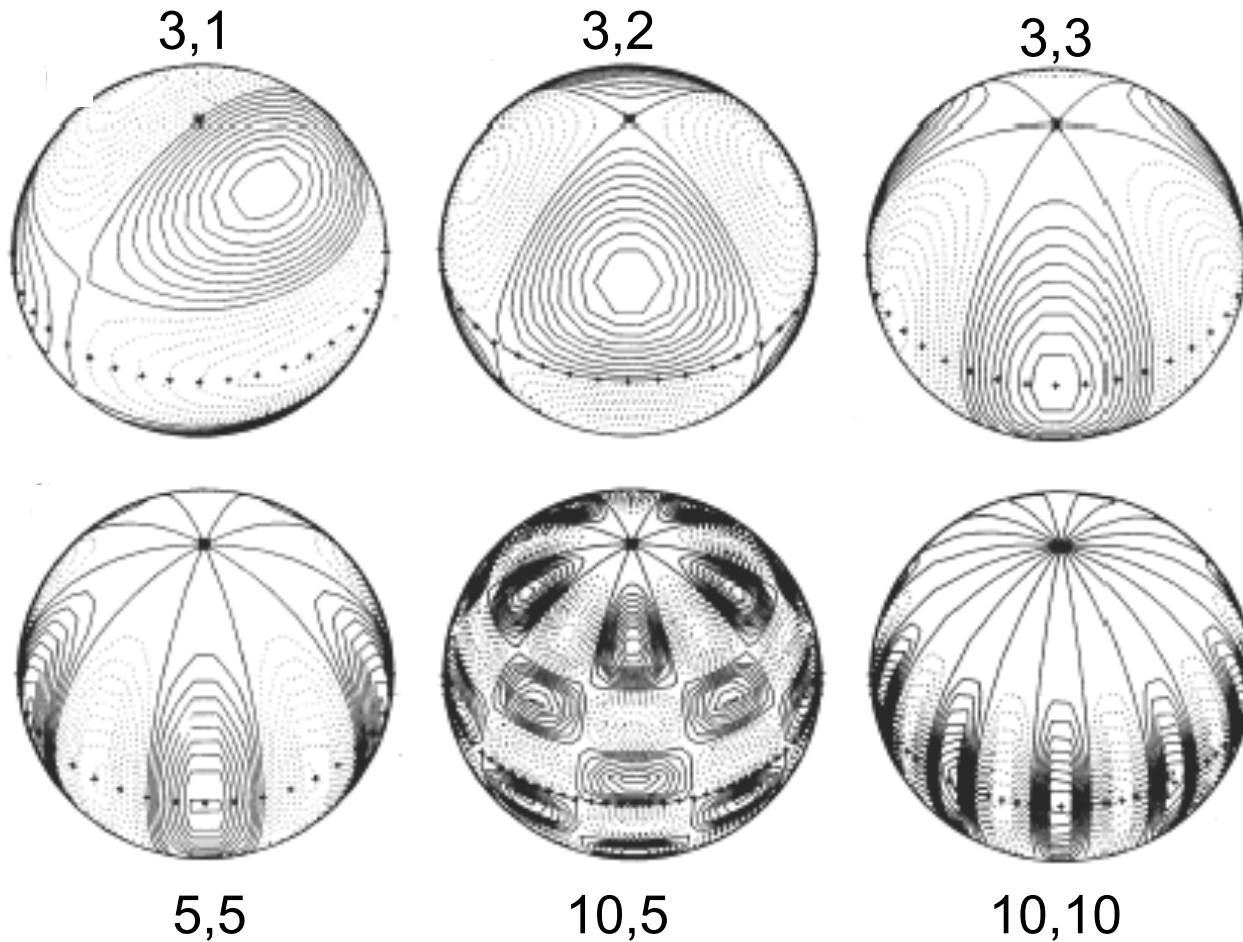
Moo



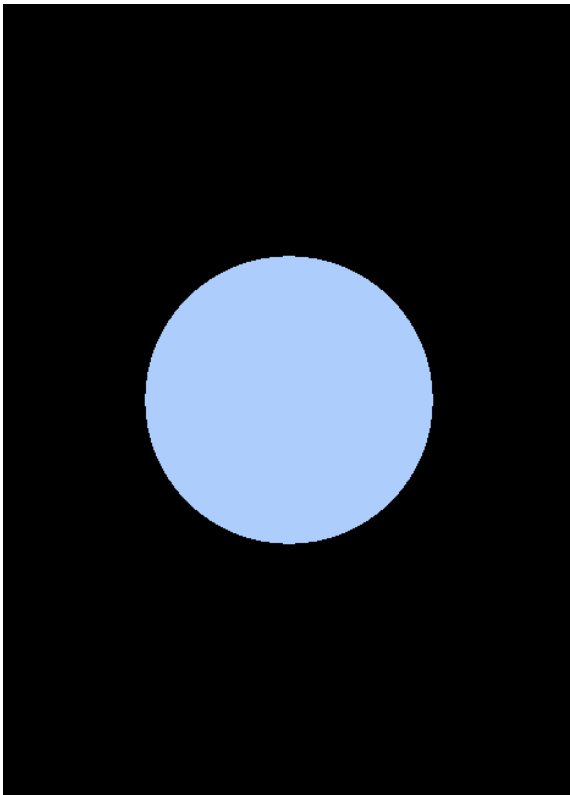
Spherical Harmonics (l, m)



Spherical Harmonics (l, m)



Pulsation timescale



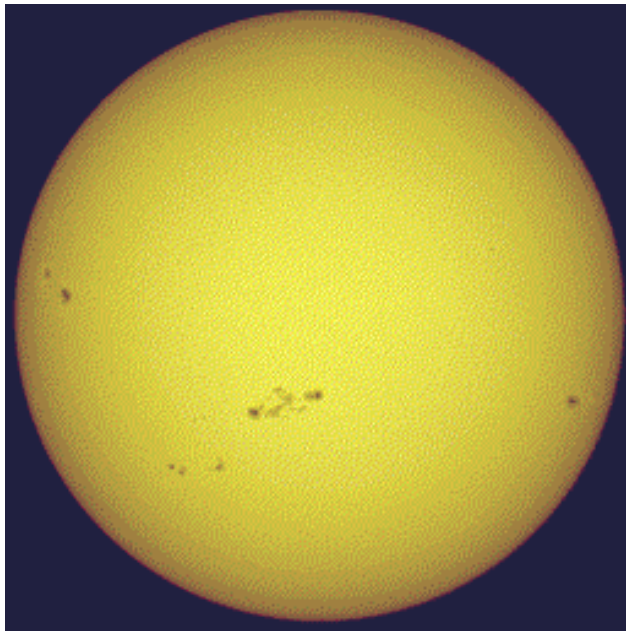
- Fundamental period of radial pulsation:

$$\Pi \propto \langle \rho \rangle^{-1/2}$$

Ritter 1880; Shapley, 1914

- Estimate period from sound crossing time
- Period similar to dynamical timescale ('free fall' time)

Pulsation timescale



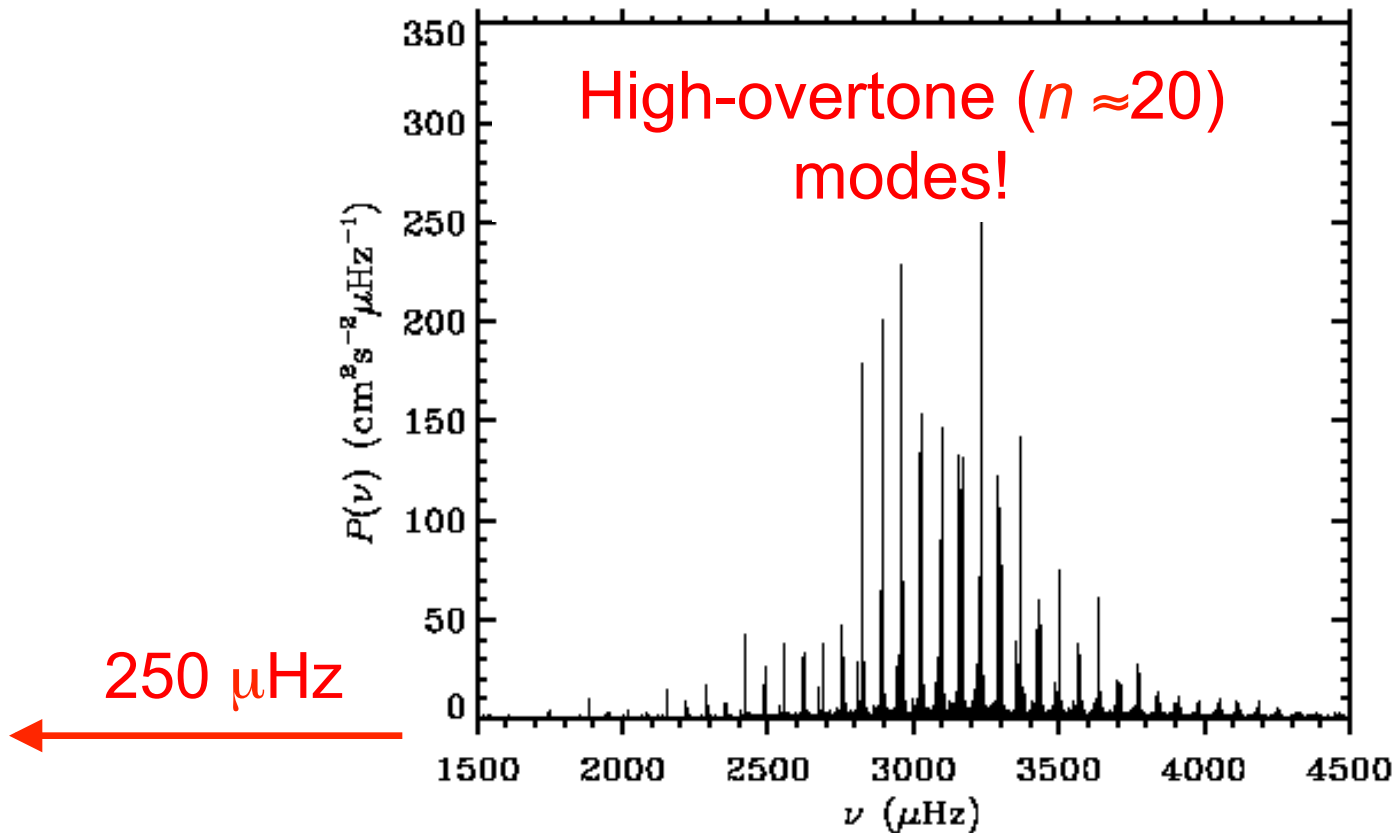
Courtesy D. Hathaway

Sun: fundamental
radial-mode period

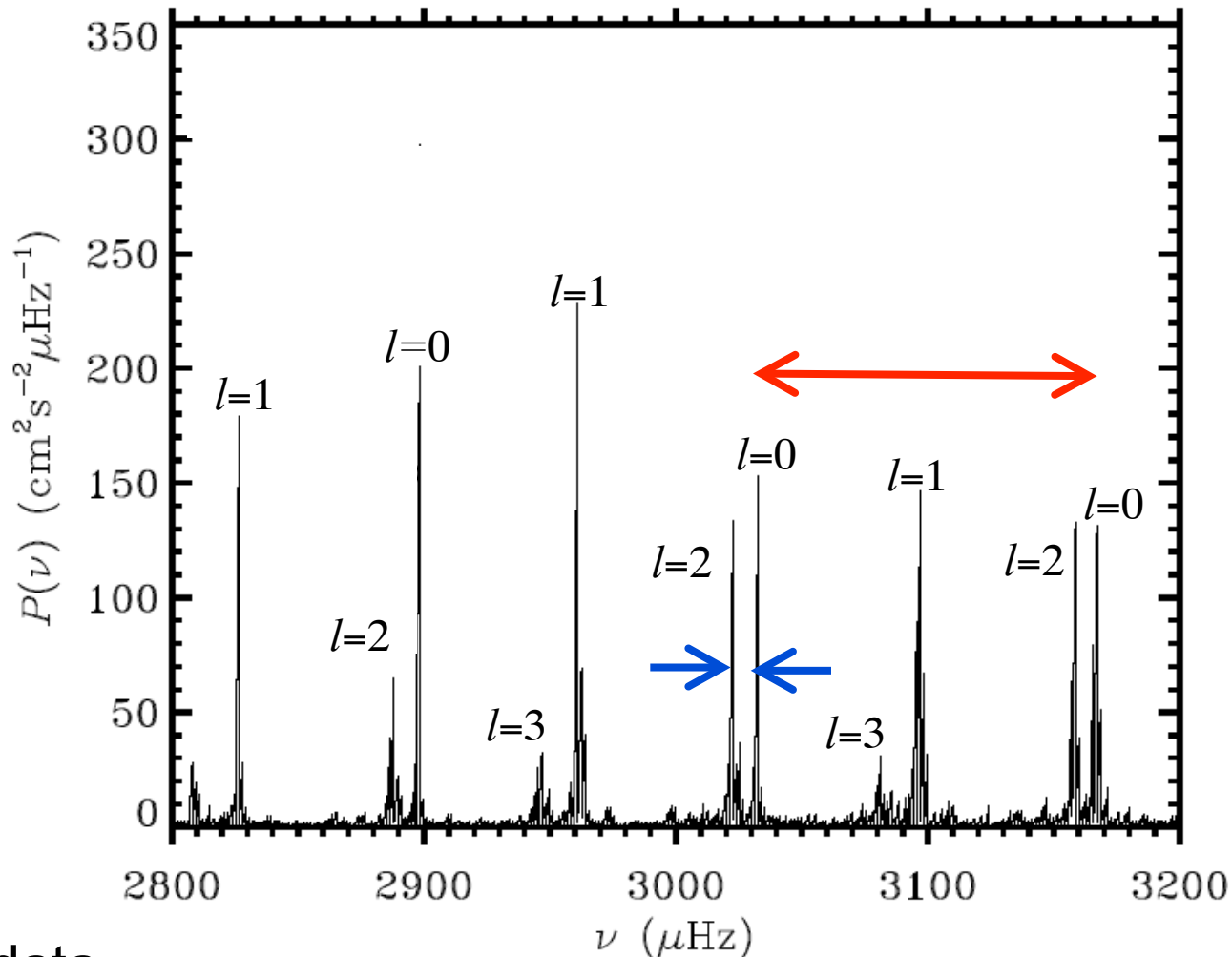
$$\Pi_f \approx 1 \text{ hour}$$

$$\nu_f \approx 250 \mu\text{Hz}$$

Frequency spectrum of low-degree (low- l) modes (contains overtones of $0 \leq l \leq 3$)

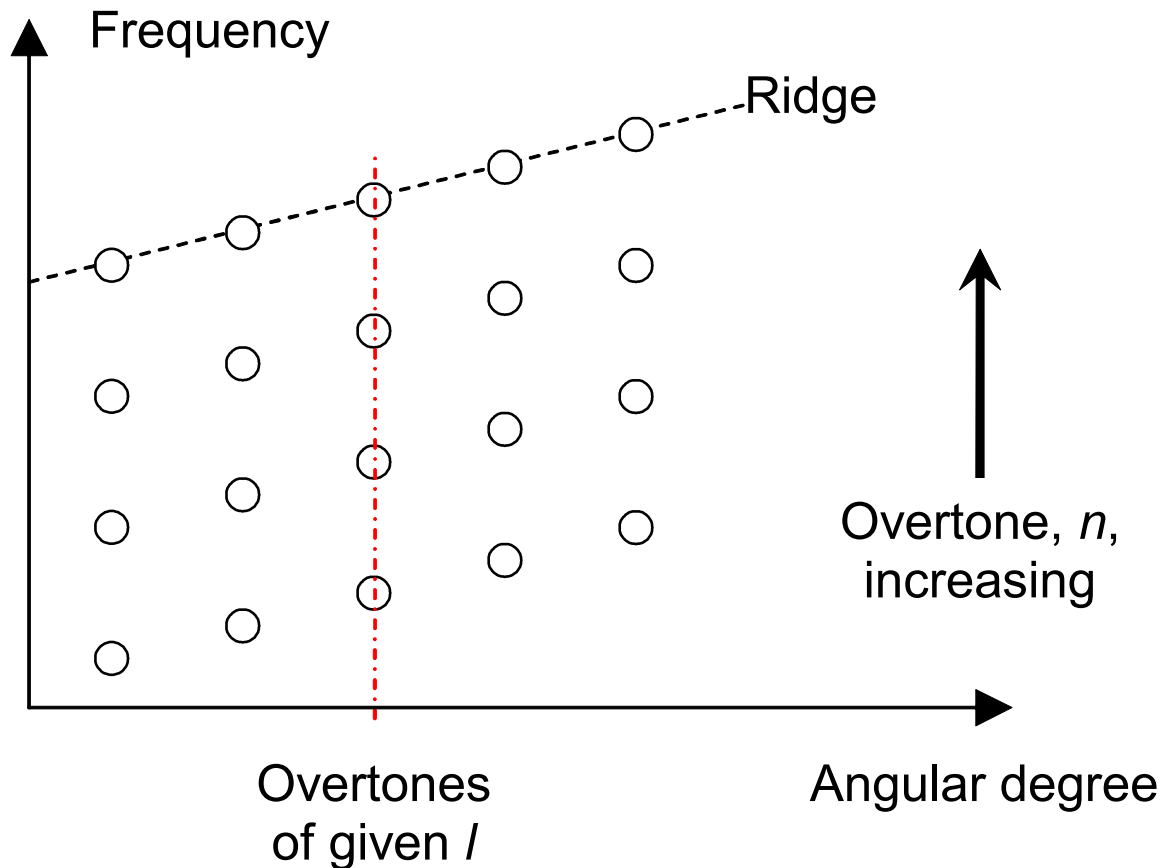


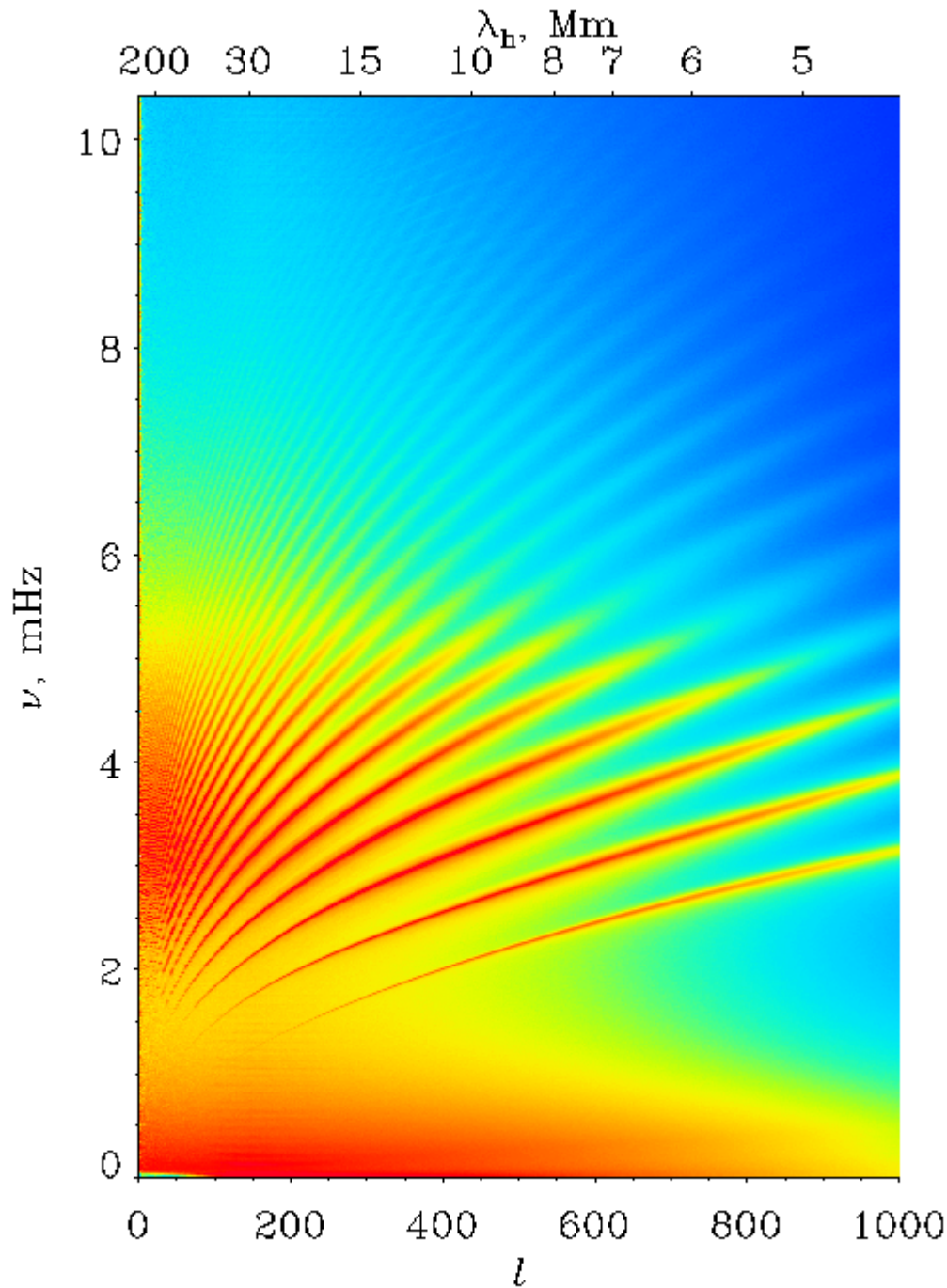
How are overtones of different degree, l , arranged in frequency?



Frequency spectrum: l - ν diagram

Consider the overtones of each degree, l

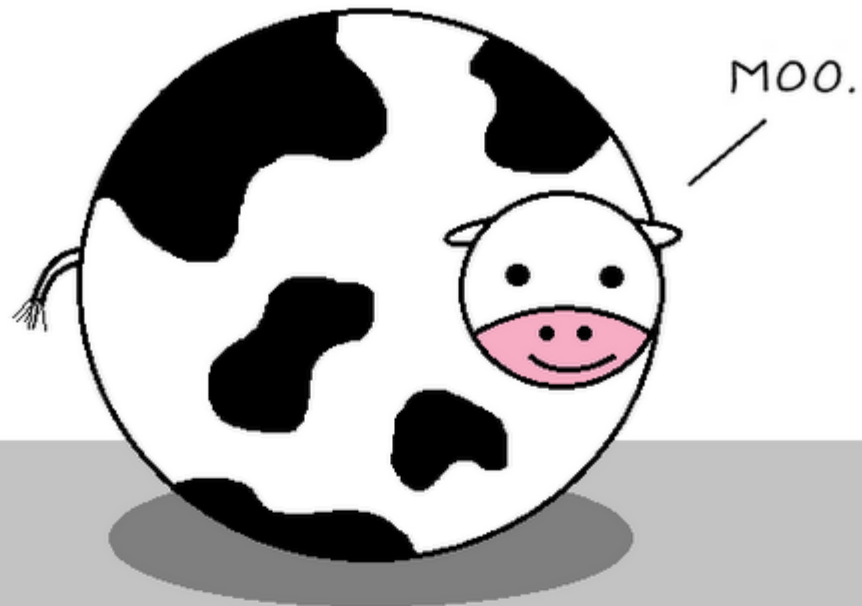




Frequency spectrum: l - ν diagram

Data collected
by MDI
instrument on
board SOHO

Assume a spherical cow of uniform density.



全吉博

Frequency spectrum: uniform non-rotating sphere

Clamped boundary conditions: displacement
fixed to zero at centre, edge

$$\nu_{nl} \approx \frac{c}{4R} (2n + l) \approx \Delta \nu (n + l/2)$$

$$\Delta \nu = \frac{c}{2R}$$

Frequency spectrum: uniform non-rotating sphere

Free boundary conditions: edges free

$$\nu_{nl} \approx \frac{c}{4R} \left(2n + l + \frac{1}{2} \right) \approx \Delta \nu \left(n + l/2 + \frac{1}{4} \right)$$

$$\Delta \nu = \frac{c}{2R}$$

Frequency spectrum: uniform non-rotating sphere

General form

$$\nu_{nl} \approx \Delta \nu \left(n + \frac{l}{2} + \varepsilon \right)$$

Frequency spectrum: Star

Stratified interior

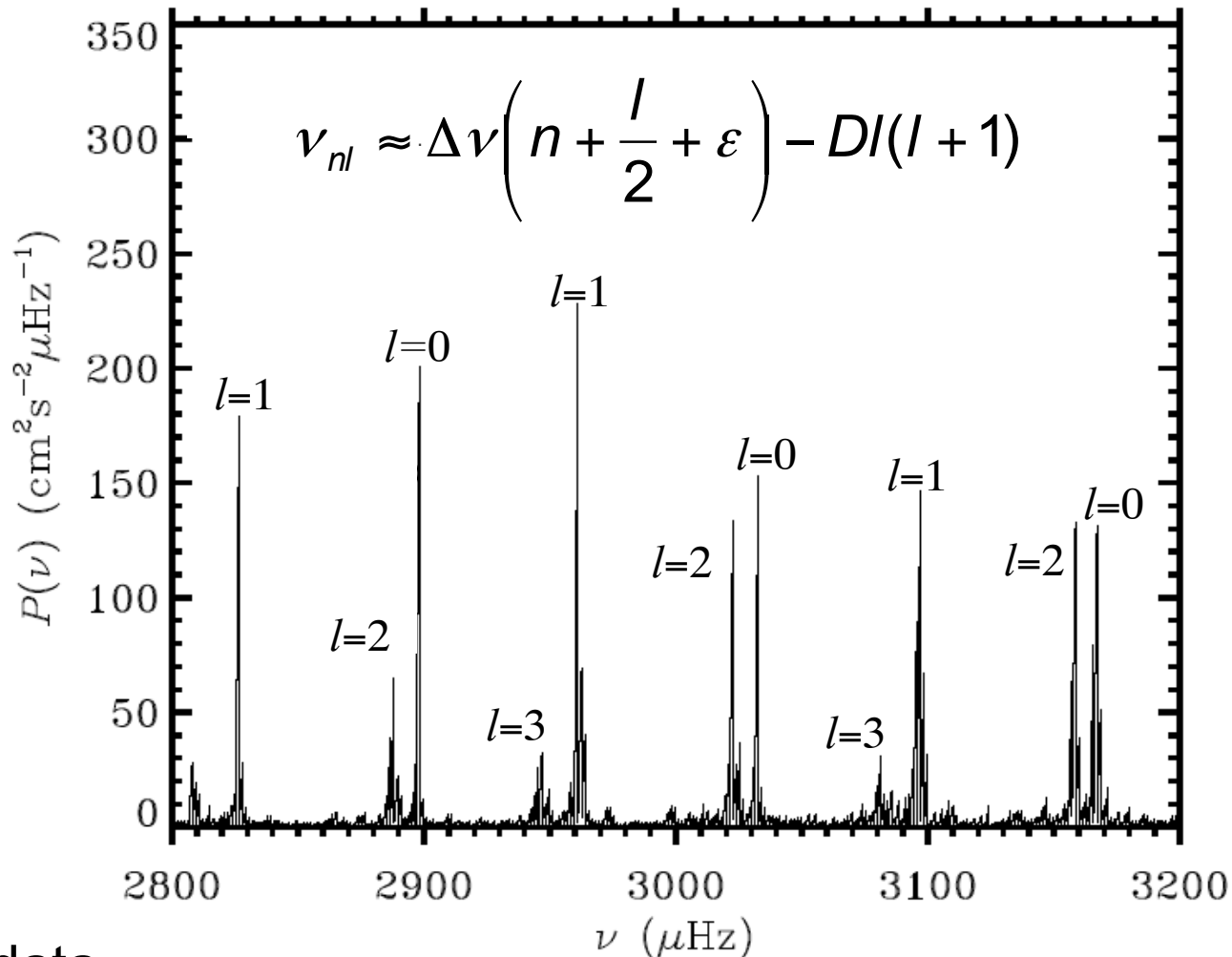
$$\nu_{nl} \approx \Delta \nu \left(n + \frac{l}{2} + \varepsilon \right) - D l (l + 1)$$

Frequency spectrum: Rotating Star

Stratified interior, slow rotation approx.

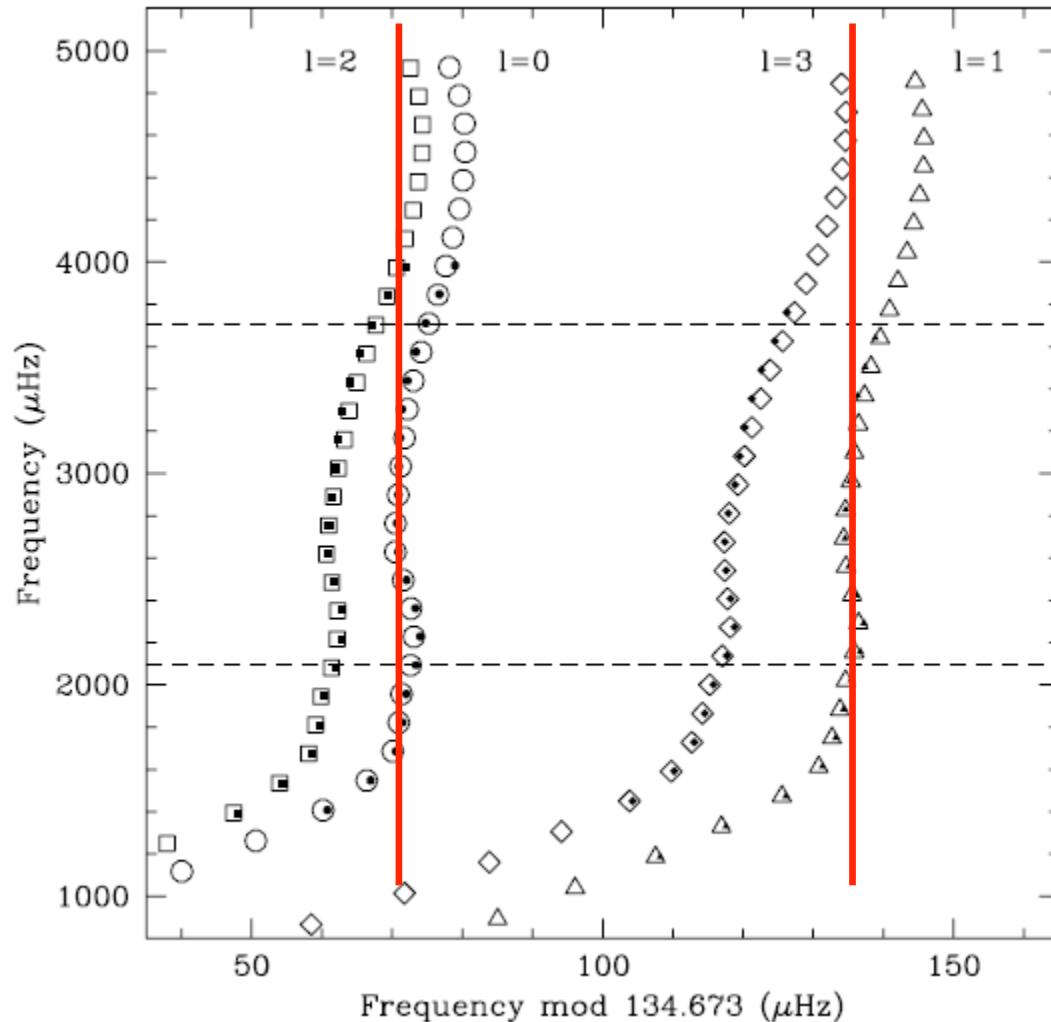
$$\nu_{nlm} \approx \Delta\nu \left(n + \frac{l}{2} + \varepsilon \right) - Dl(l+1) + m\Delta\nu_{\text{rot}}$$

How are overtones of different degree, l , arranged in frequency?



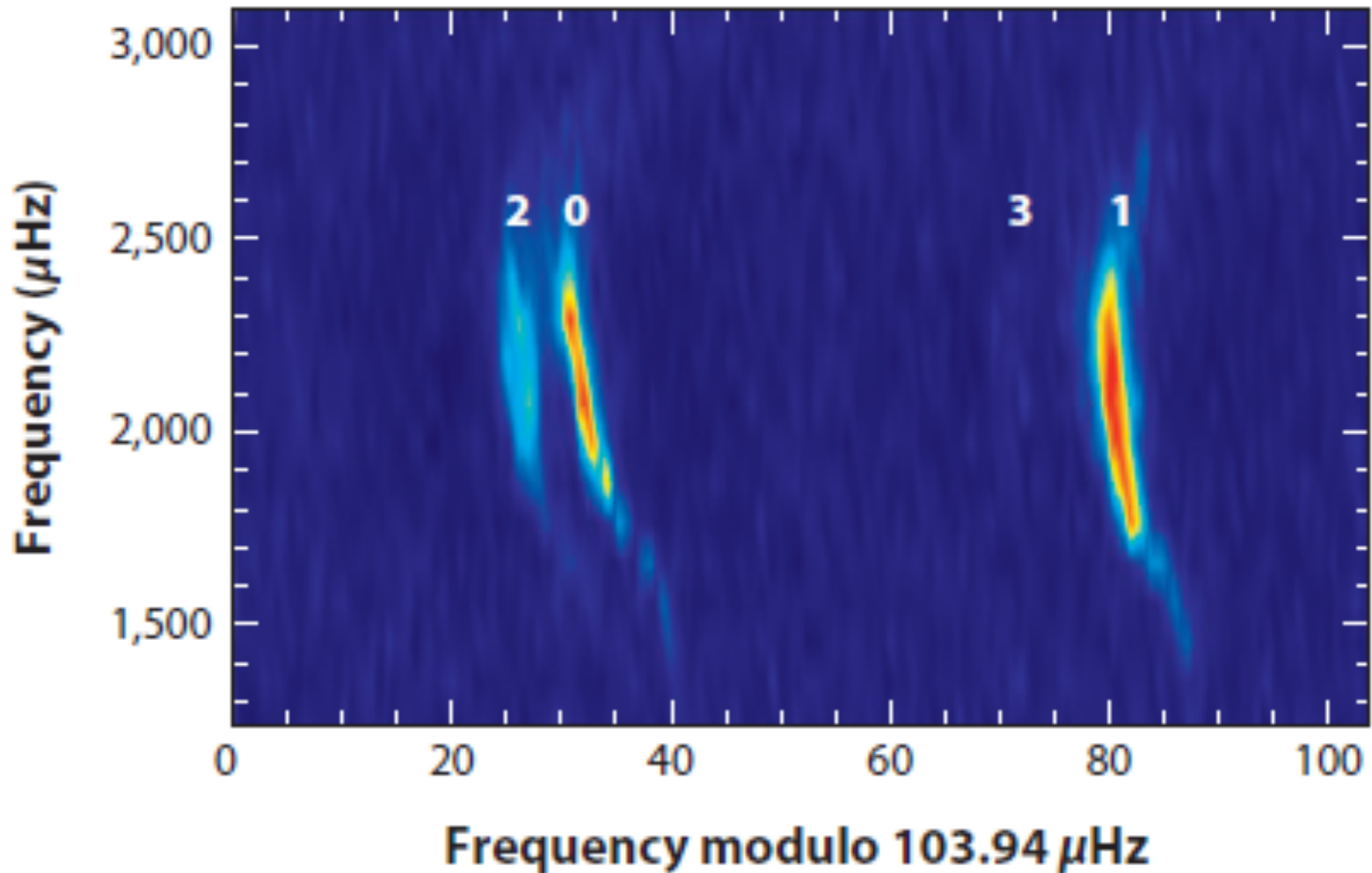
Échelle frequency plot

BiSON Sun-as-a-star + model frequencies



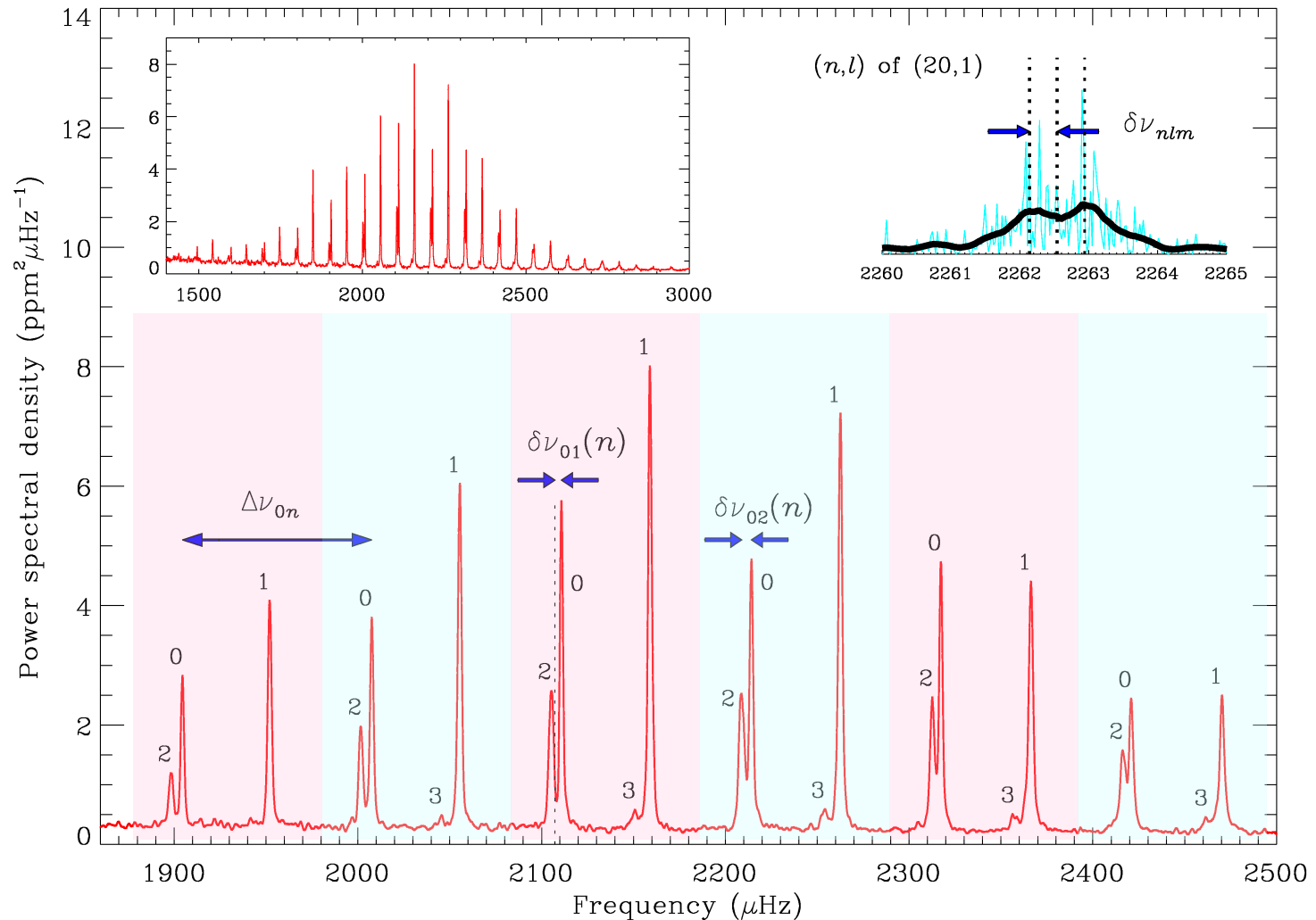
Kepler's “best in class”

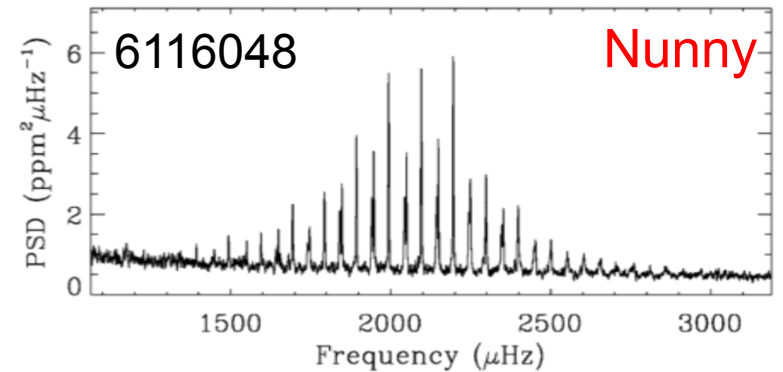
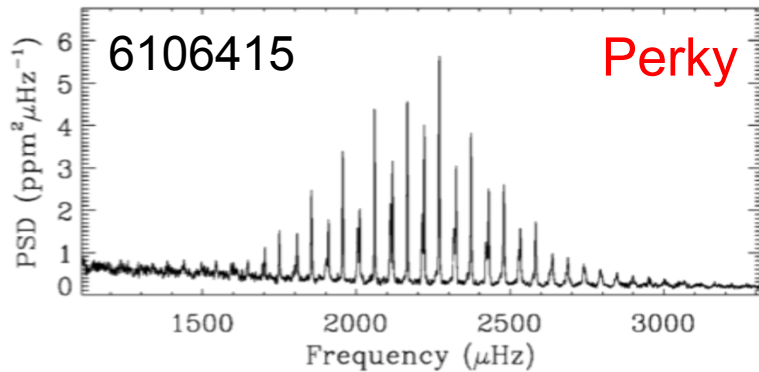
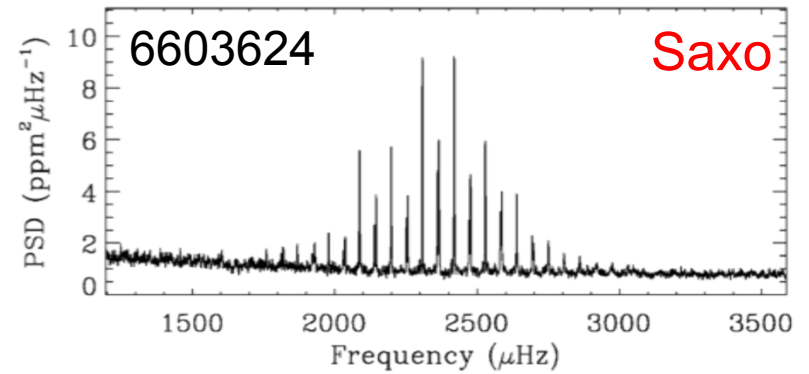
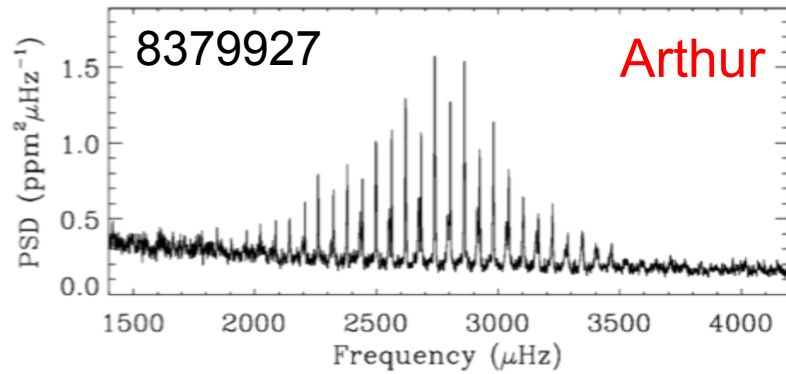
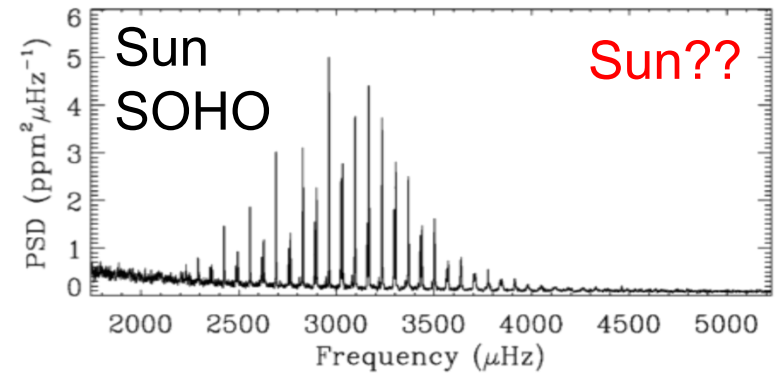
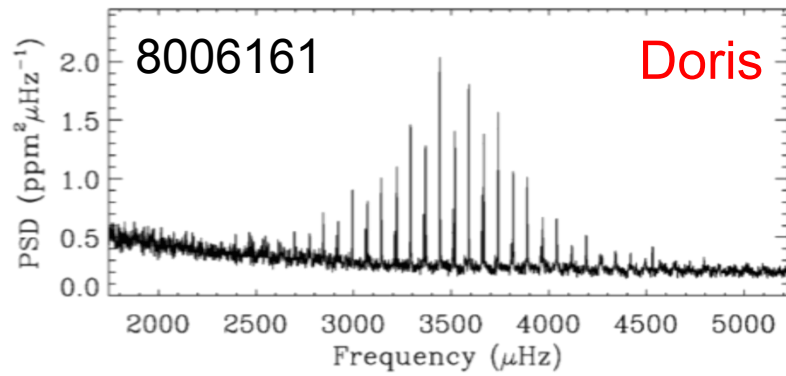
The A-component of the solar-type binary 16 Cyg

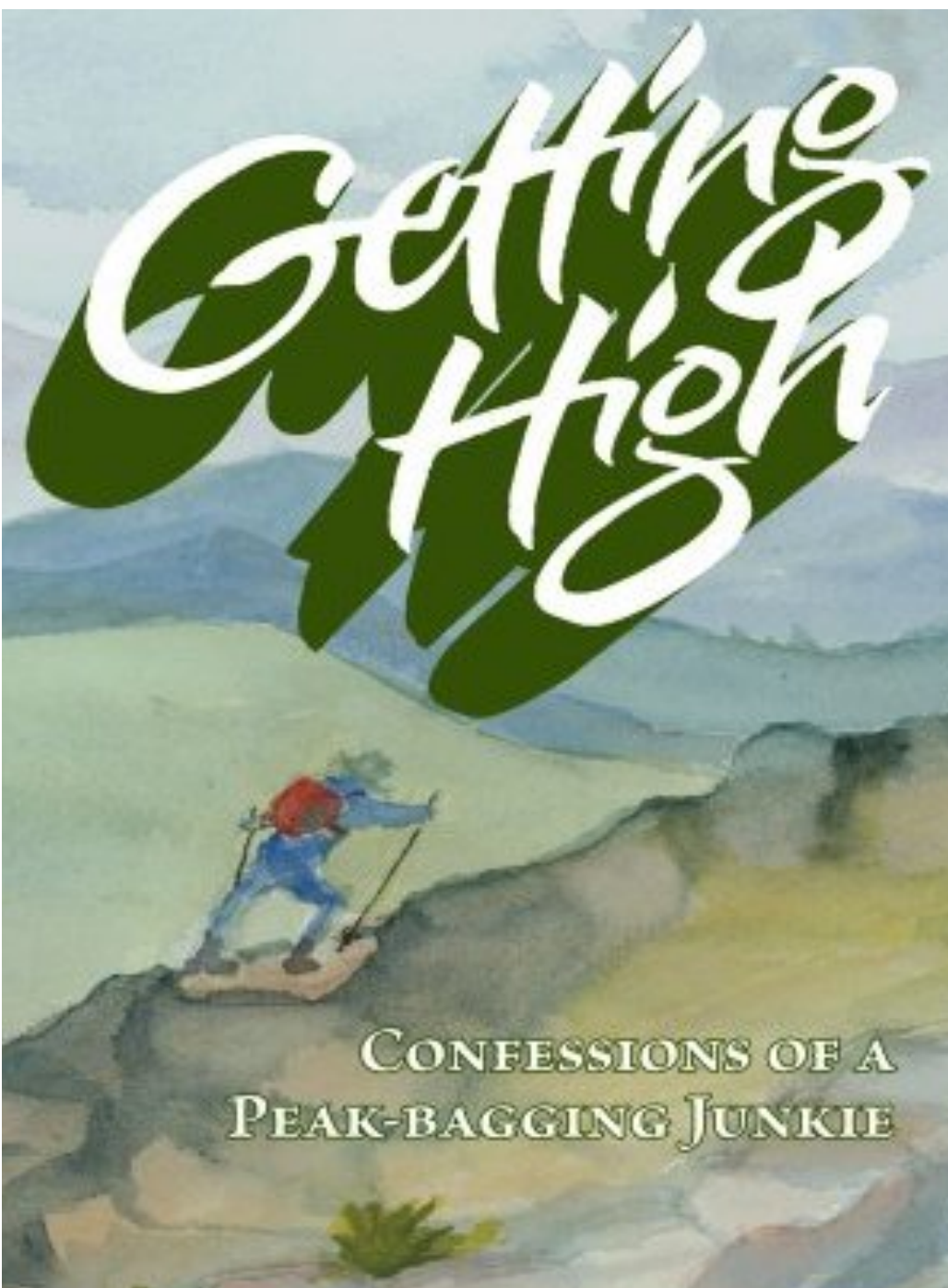


Kepler's "best in class"

The A-component of the solar-type binary 16 Cyg



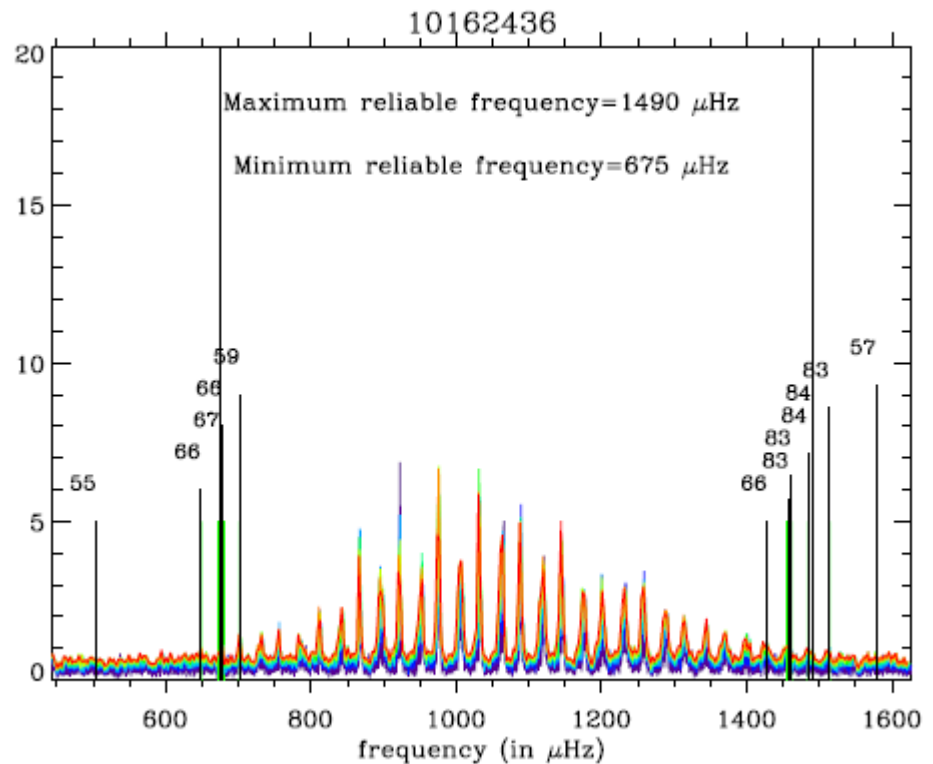
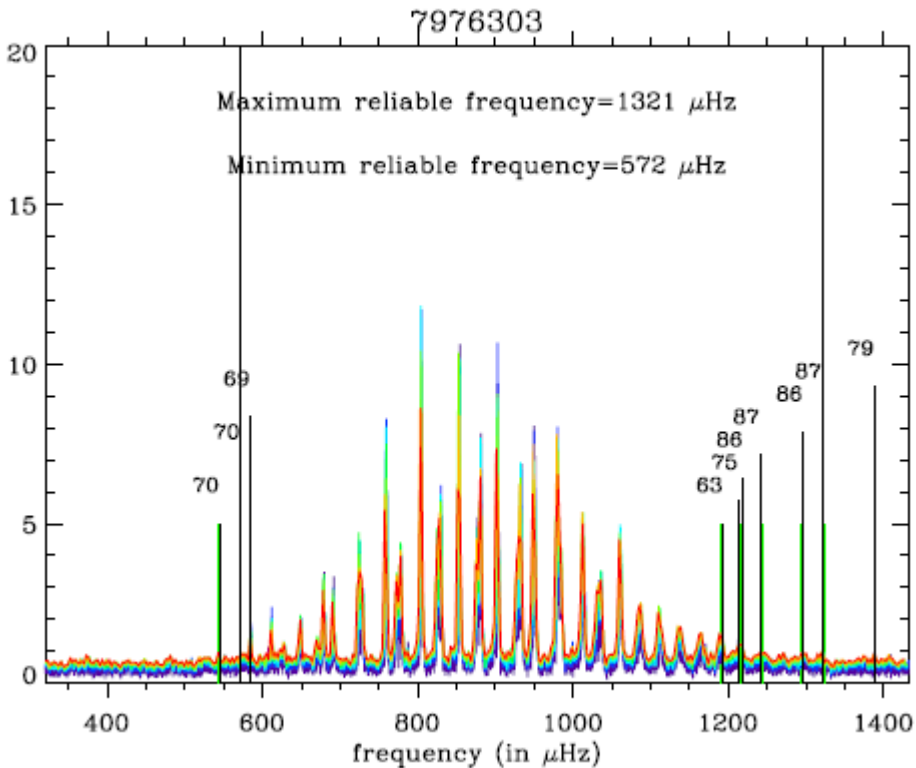




“Getting High—
Confessions of
a Peak-Bagging
Junkie”

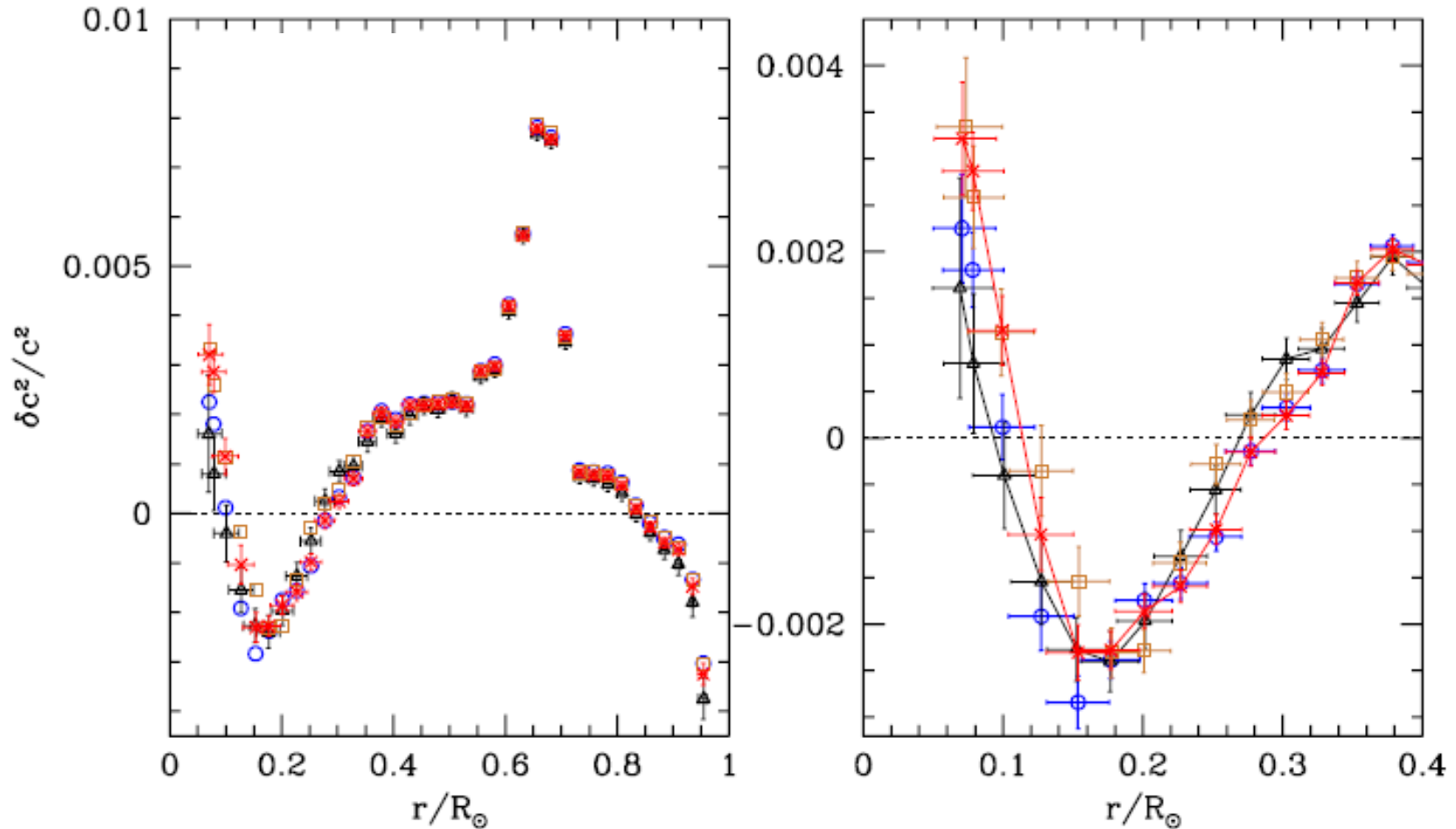
Toward automated peak-bagging of Sun-like stars

Homogeneous analysis of 61 solar-type stars

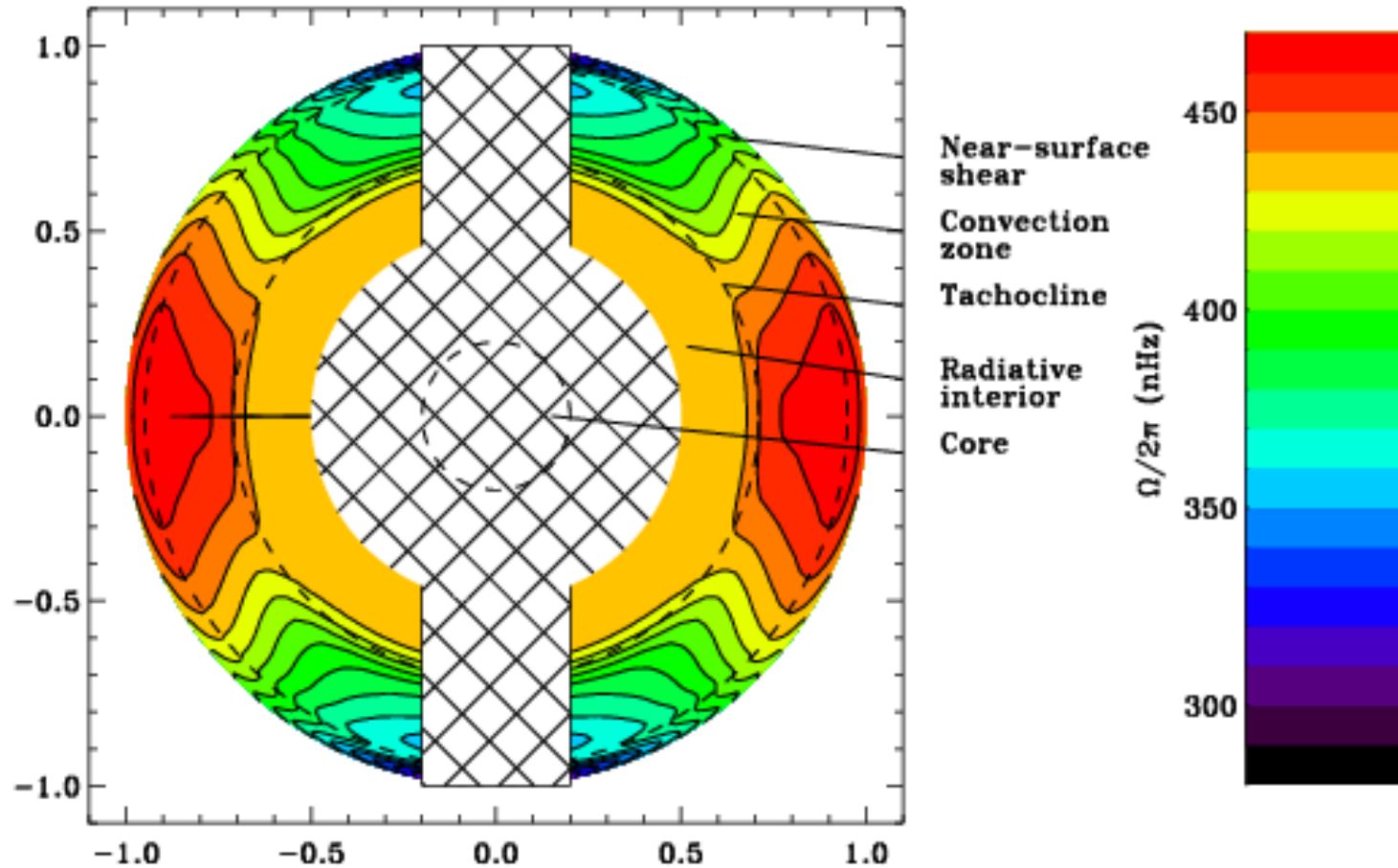


Fractional sound-speed differences: observed minus model

BiSON + MDI data



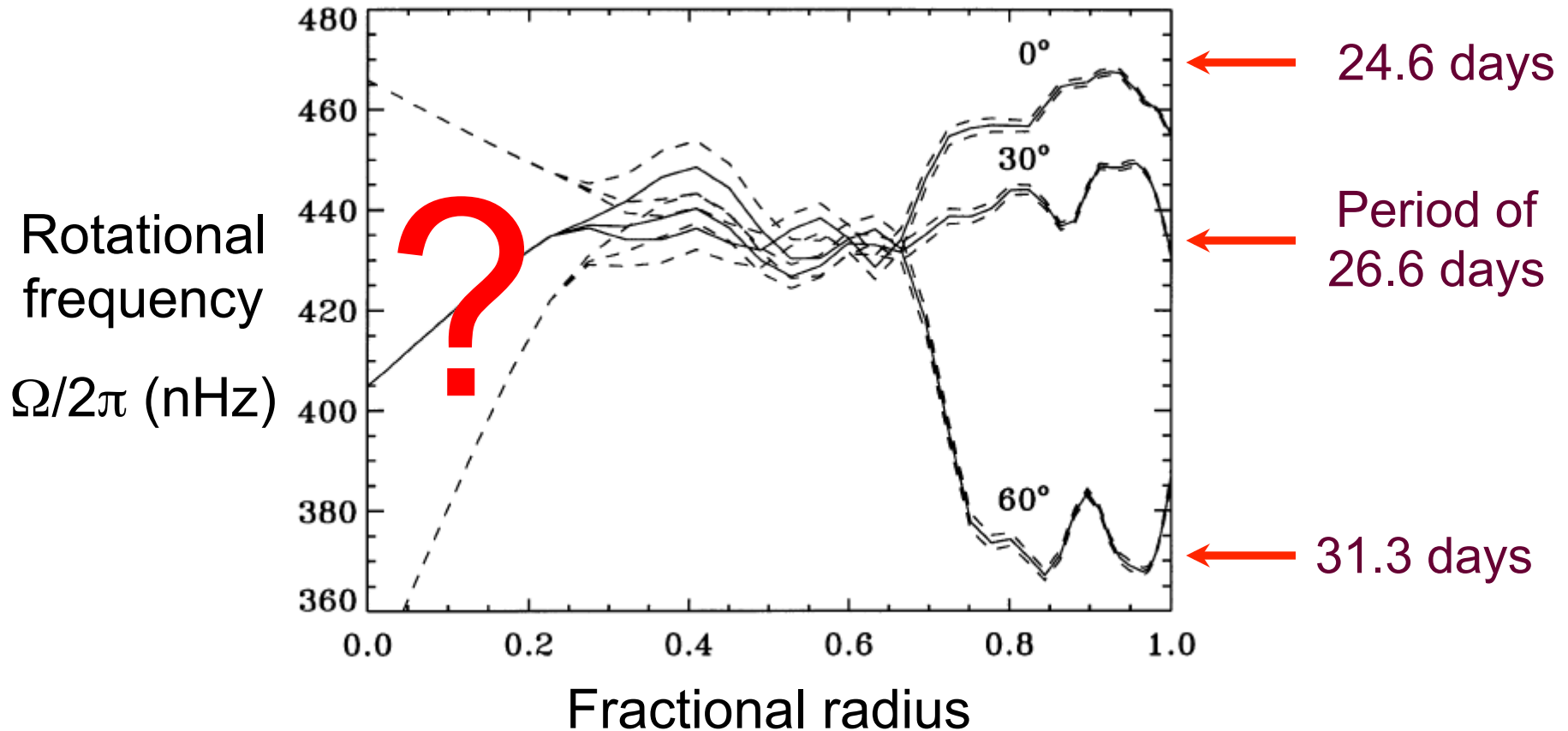
Internal Solar Rotation



GONG data

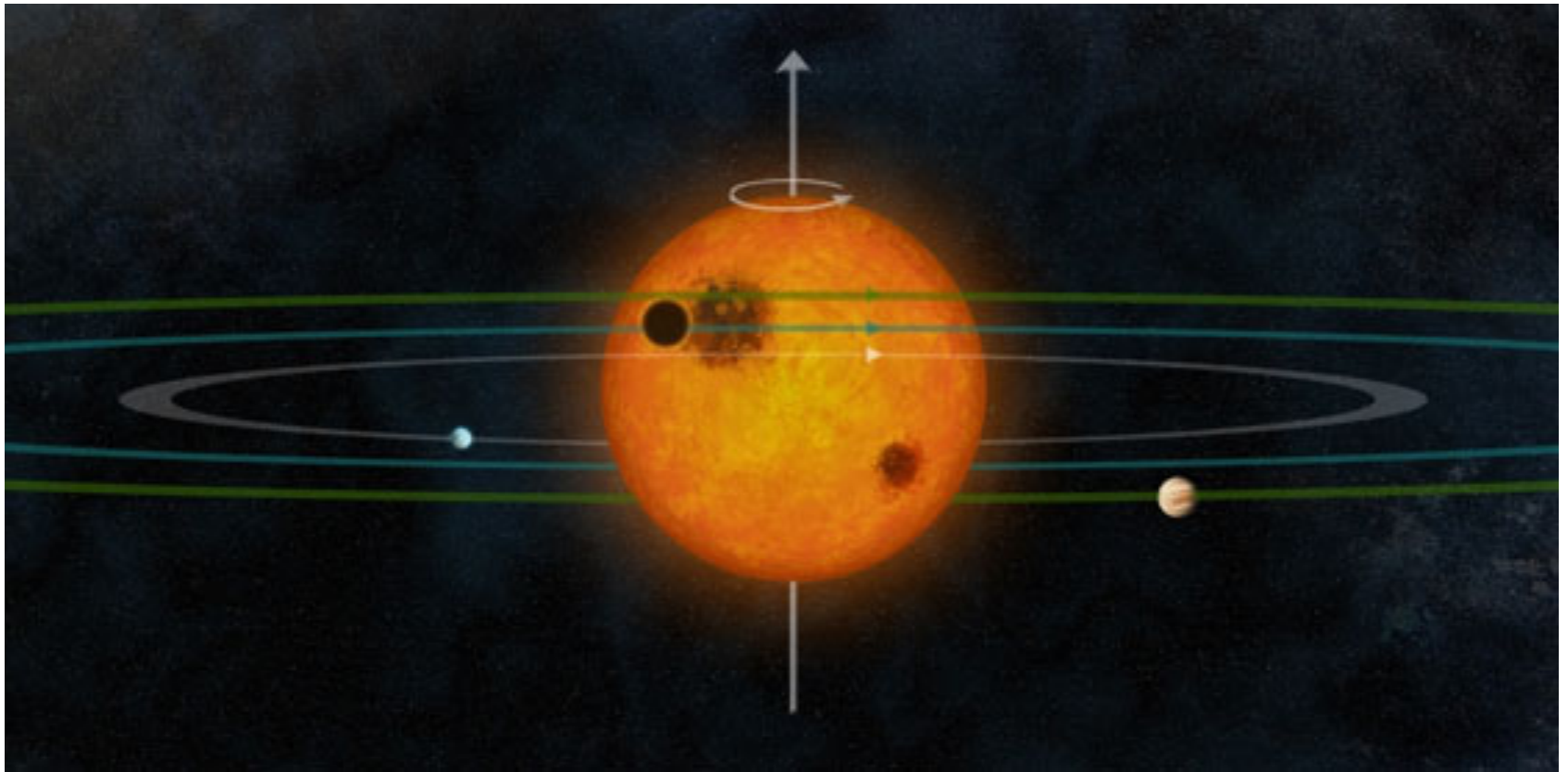
Rotation of the Deep Interior

BiSON + SOI/MDI data



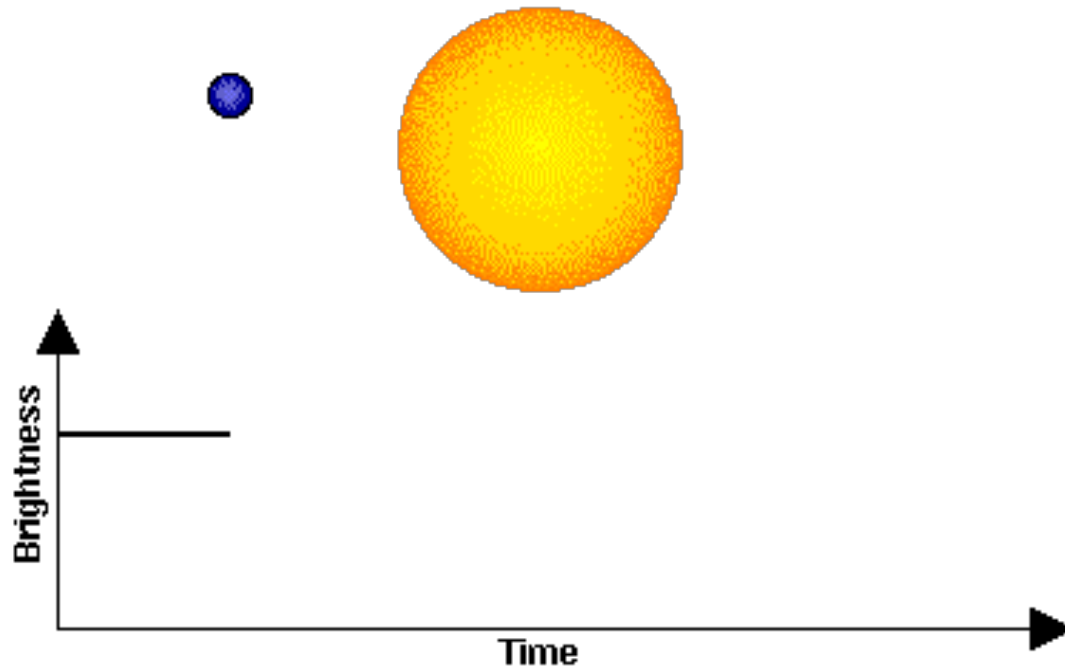
Spin-orbit alignment

Asteroseismology constrains inclination of stellar spin axis



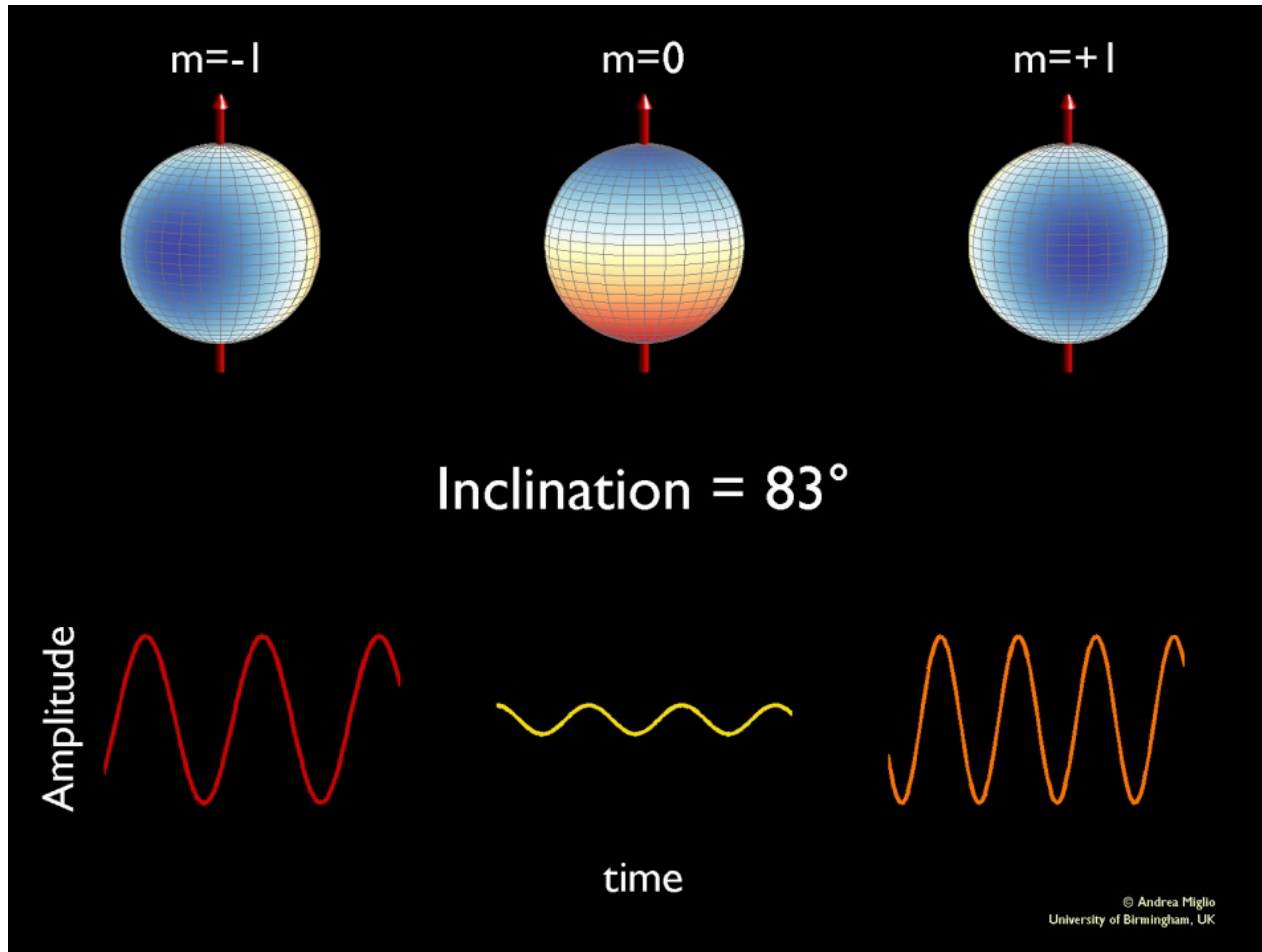
The “transit method”

Detection of extra-solar planets



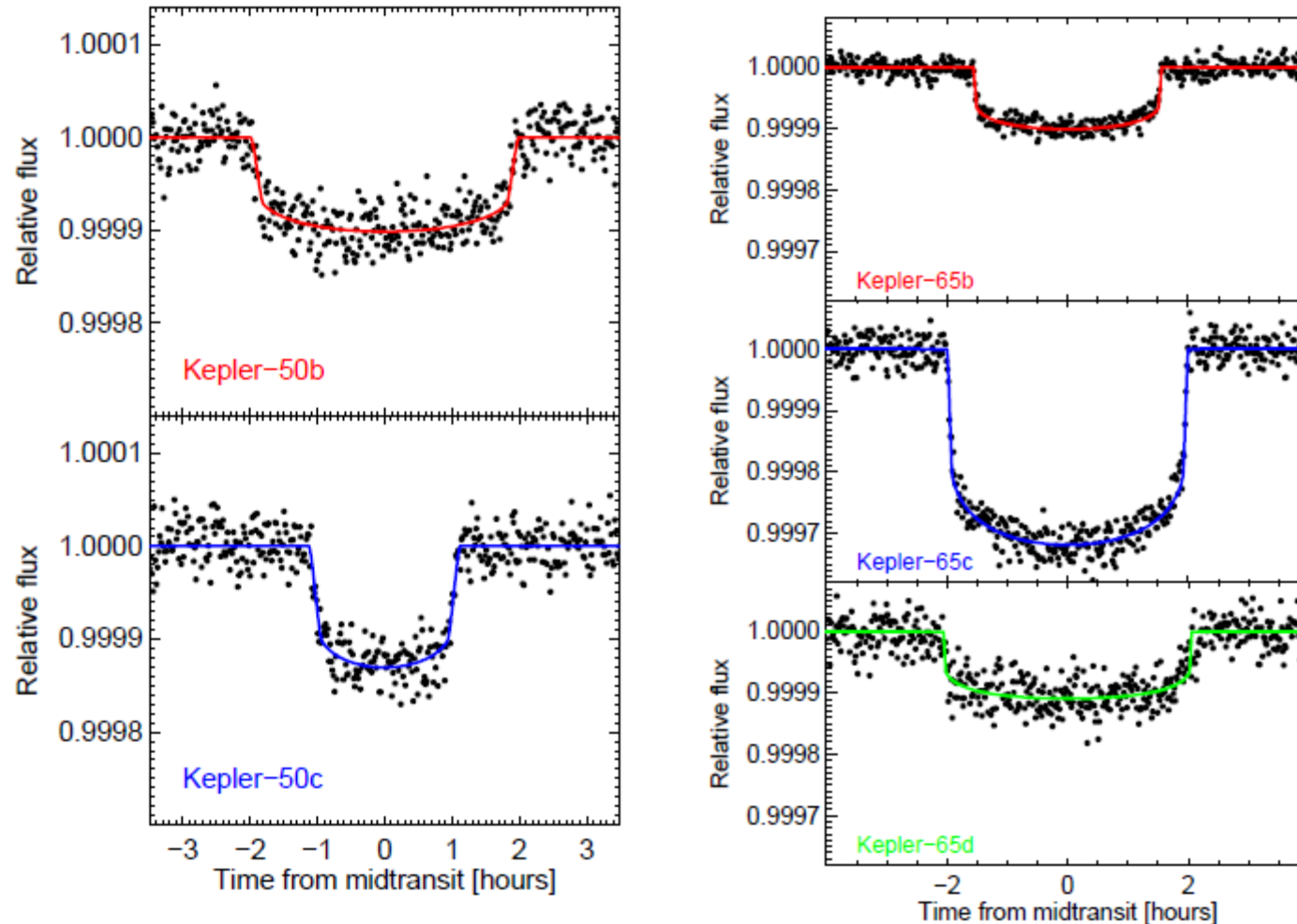
Inference on stellar inclination

Example: dipole mode of oscillation



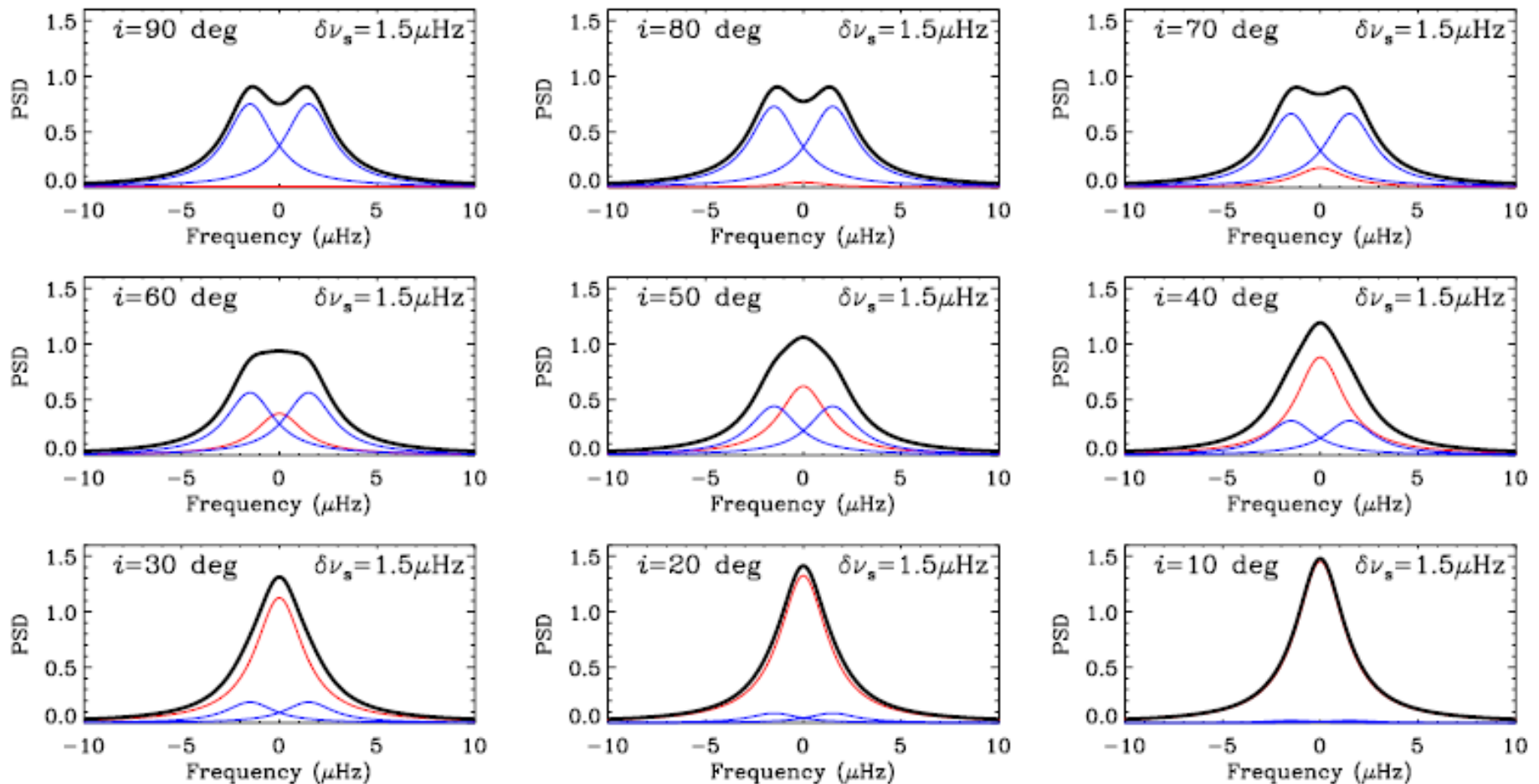
Kepler-50 and Kepler-65

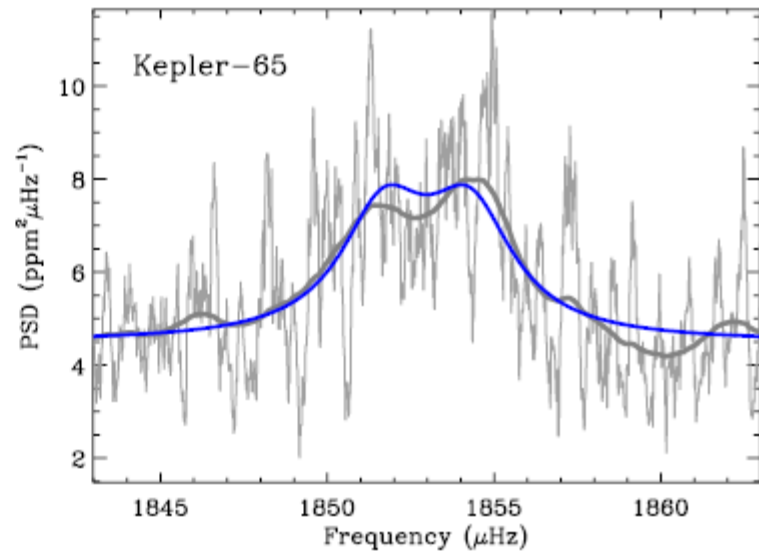
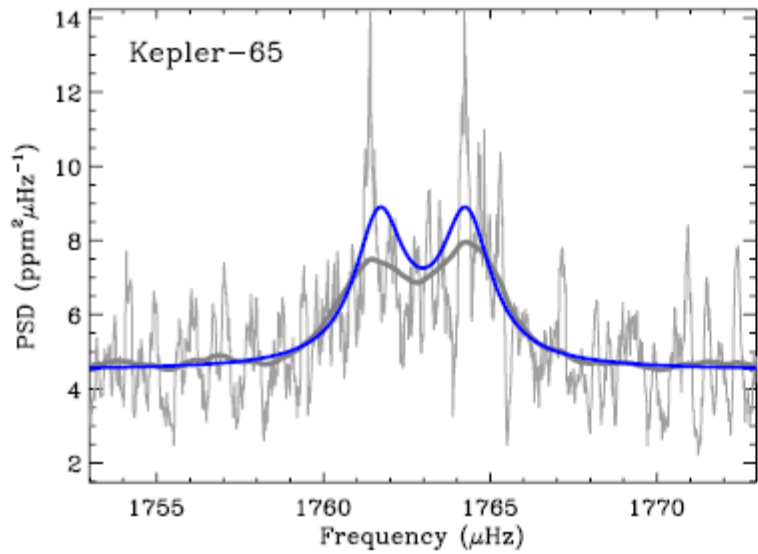
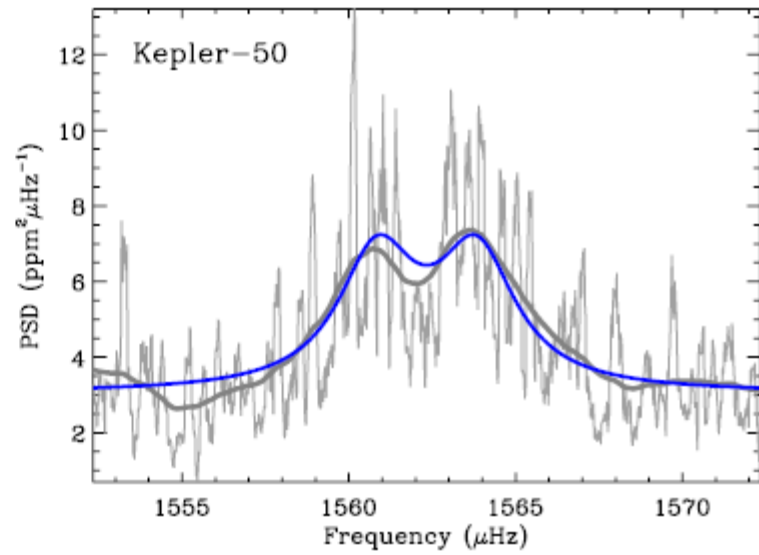
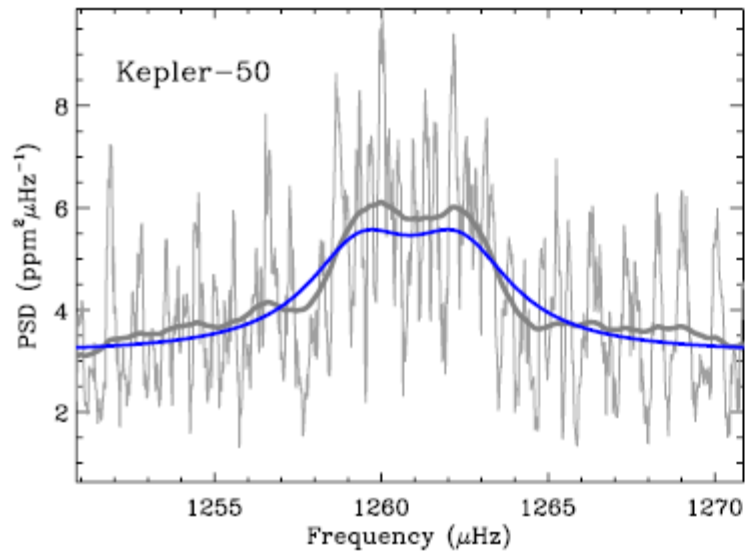
Two stars with multiple small planets



Inference on stellar inclination

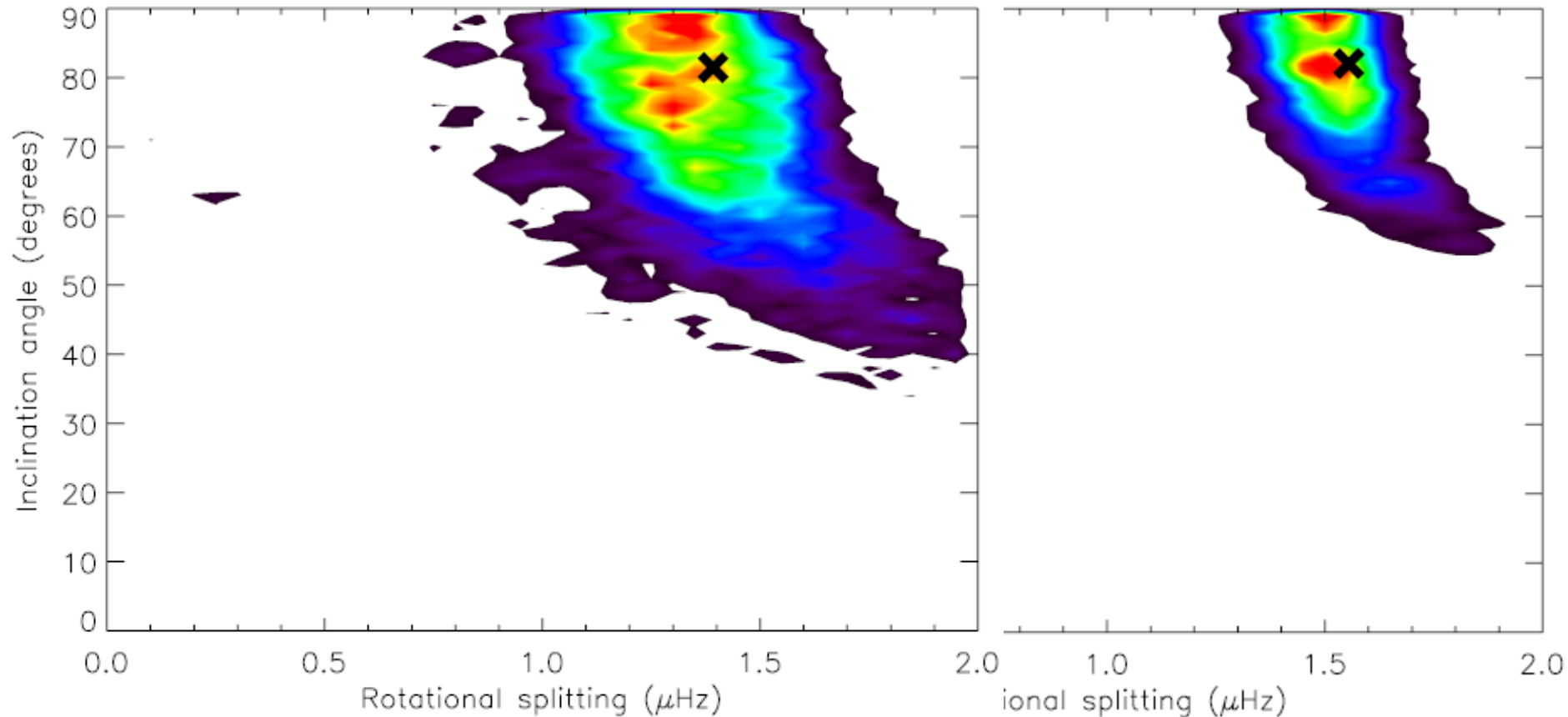
Example: dipole oscillation mode





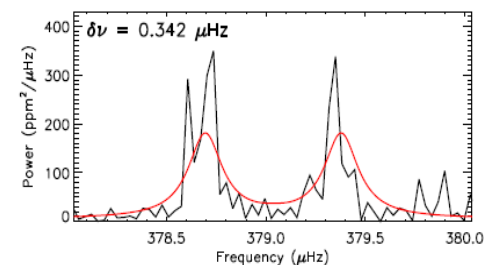
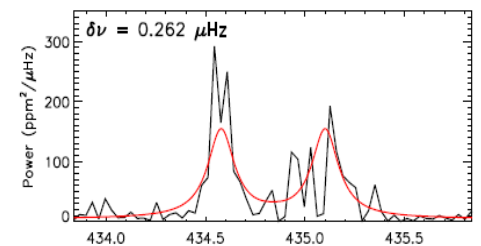
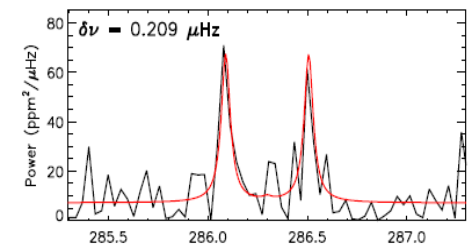
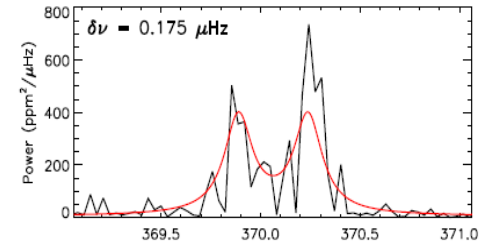
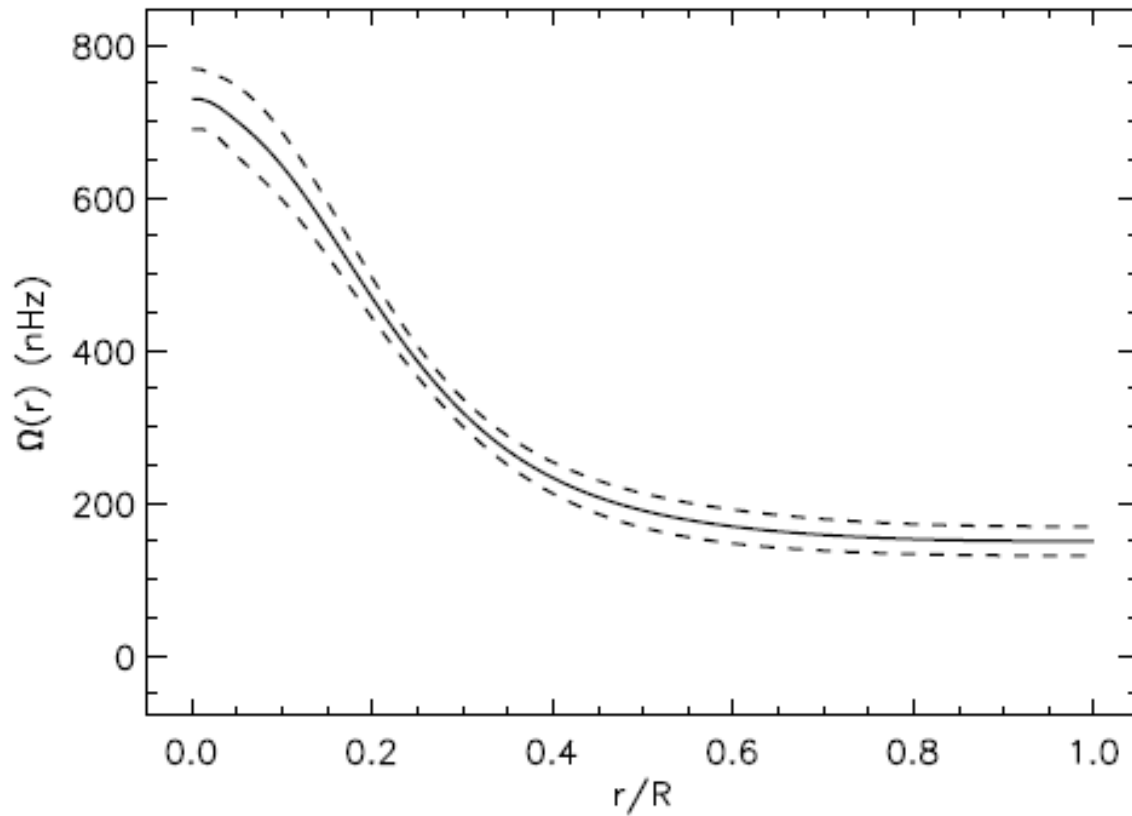
Kepler-50 and Kepler-65

Two stars with multiple small planets



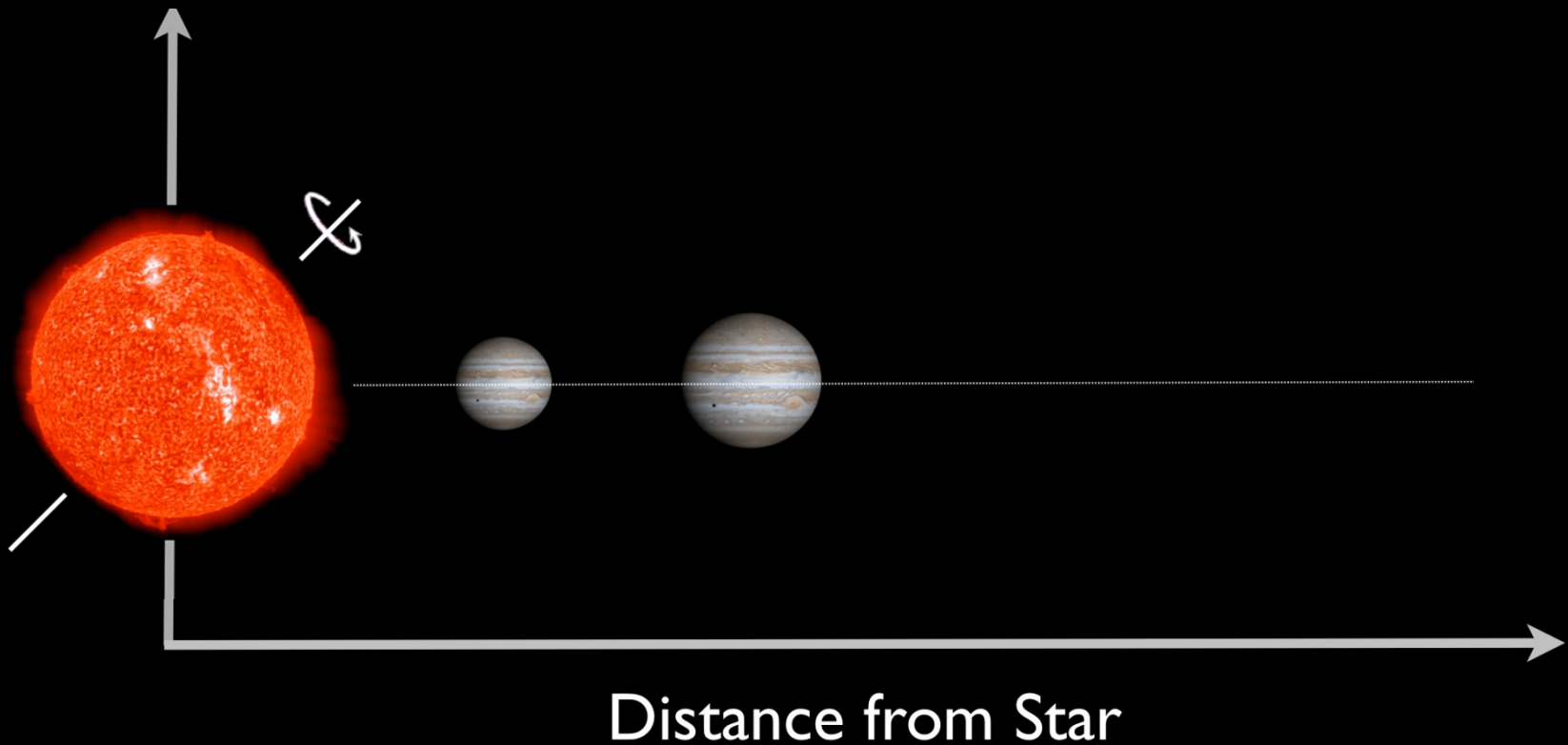
Internal rotation of a subgiant

Core rotates five-times faster than surface



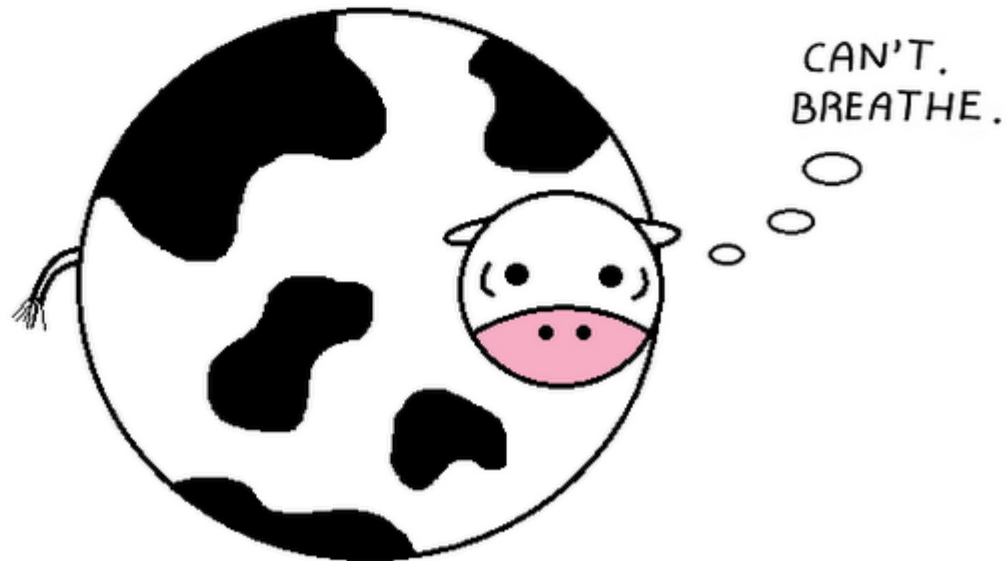
Kepler-56

A misaligned multi-planet system
with a red-giant host star



End

...in a vacuum.



XXXXXXXXX theoretical physicists

How do you sleep at night?